A statistical bias correction of precipitation and temperature to enhance simulations of the current and future hydrological cycle

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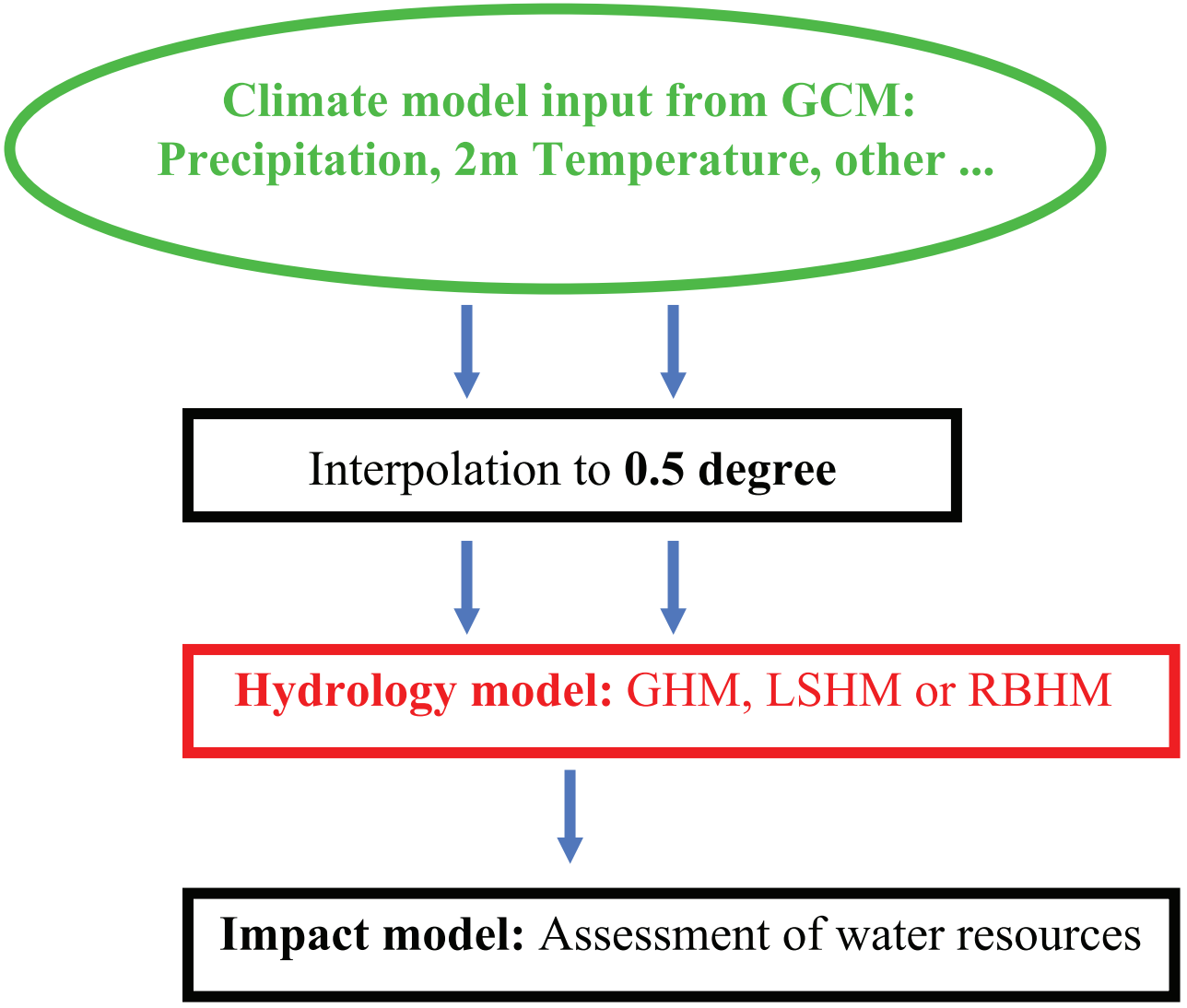
Overview

- Climate model – Hydrological model (HM) modelling chain
- Global statistical bias correction of Precipitation and Temperature
- Robustness of bias correction method
- Summary and Future Work
- Application to REMO UBA data over Germany

Global modelling chain in WATCH



Bias correction required

- Bias correction should be applied to GCM data
- As large scale extremes shall also be considered, a simple correction of the mean values is not sufficient.
- Bias correction is required that corrects the whole distribution.

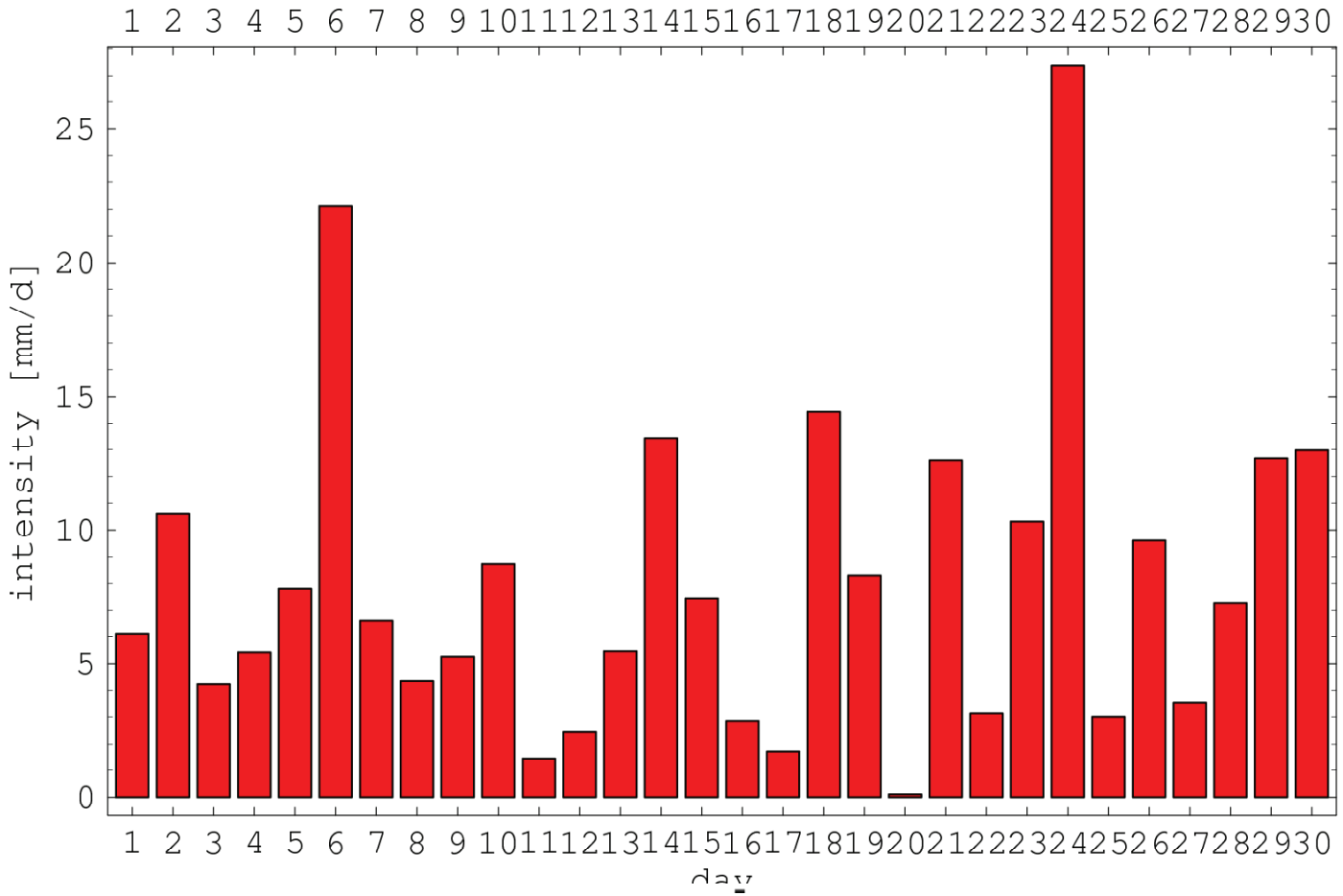
Bias correction – main assumptions

- Quality of observational datasets limits the quality of the bias correction.
- It is assumed that the bias behaviour of the model does not change with time, i.e. the transfer function is time-independent and, thus, applicable in the future.
- Limitation: Temporal errors of major circulation systems can not be corrected, e.g. onset of monsoon.

Methodology for statistical bias correction of precipitation and temperature time-series

- Based on Piani, C., J.O. Haerter and E. Coppola (2009) Statistical bias correction for daily precipitation in regional climate models over Europe. Theor. Appl. Climatol, DOI 10.1007/s00704-009-0134-9
- Piani et al. (incl. JO.Haerter, S. Hagemann) (2010): Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models. Submitted to J. Hydrology

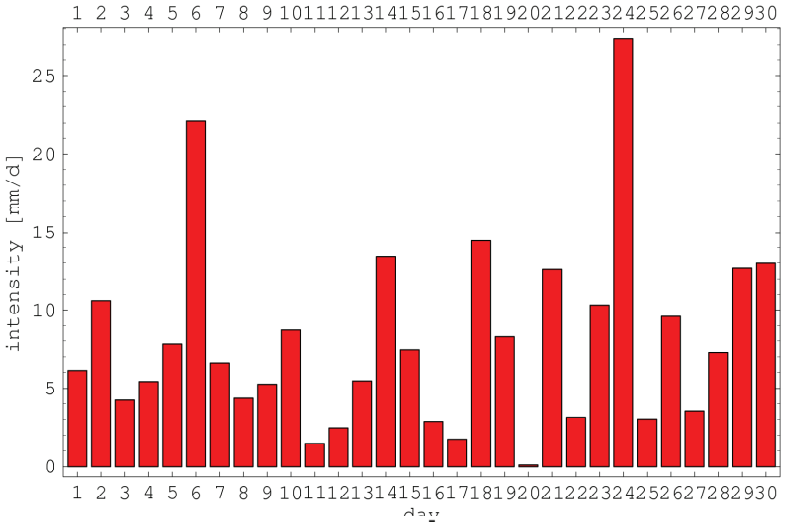
Observed daily precipitation time series



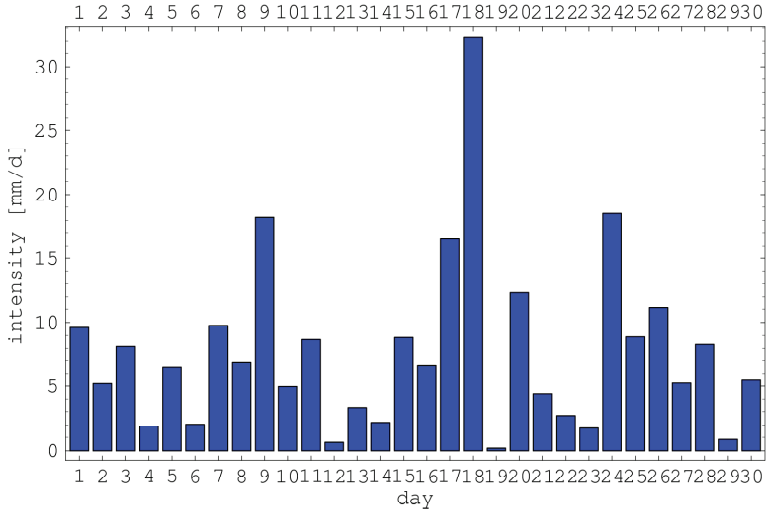
- such time-series are produced for **every single grid-point** on the globe

Observed and modeled time series

observed



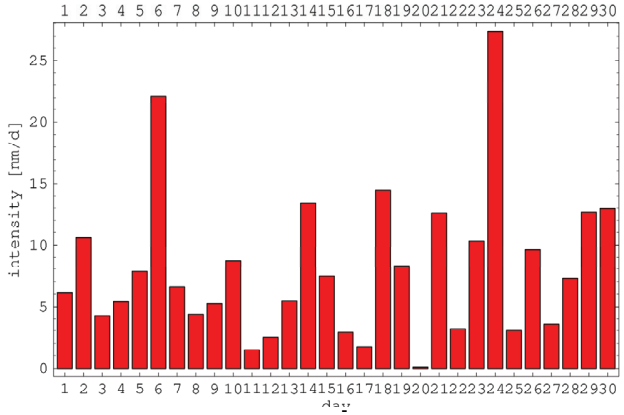
modeled

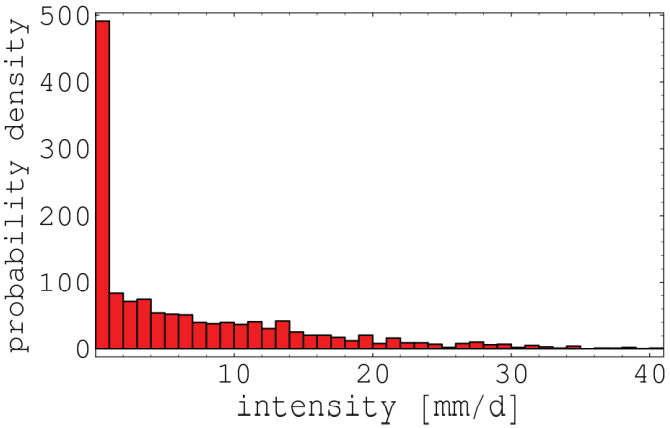


- a day-by-day comparison of observed and modeled data is not possible
- but climate is defined by the statistics of the data
- a bias-correction should impact on the **climatological statistics** of the time-series

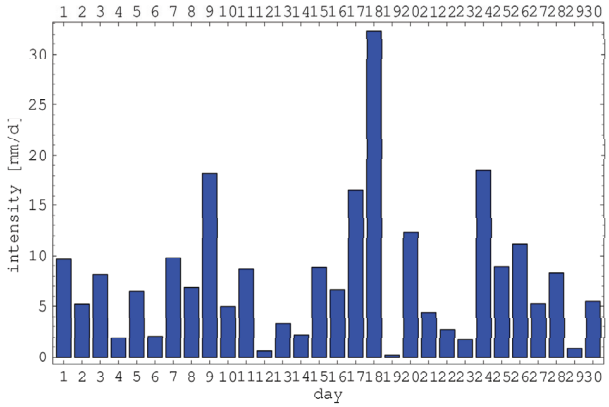
Observed and modeled time series

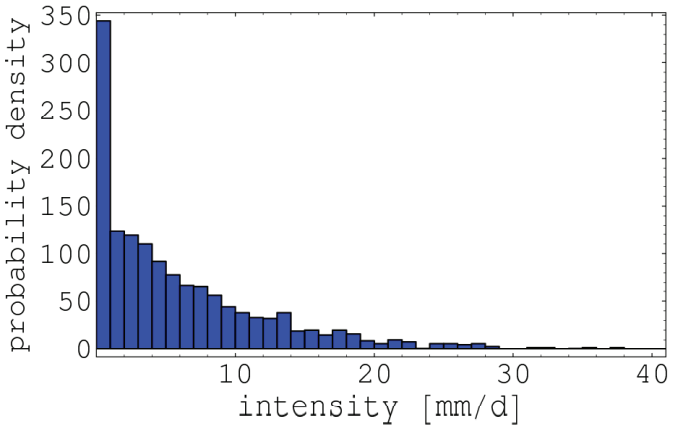
observed





modeled



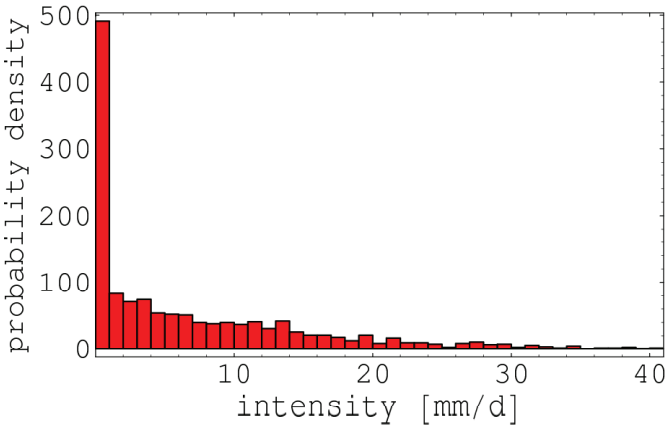


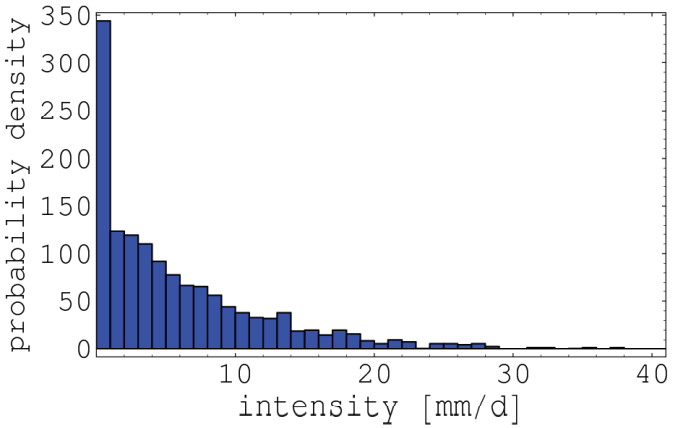
- produce histograms (probability density functions) of observed and modeled data
- many days are dry days (spike at zero intensity)

Observed and modeled time series

observed **modeled**

now we are independent of the time-series





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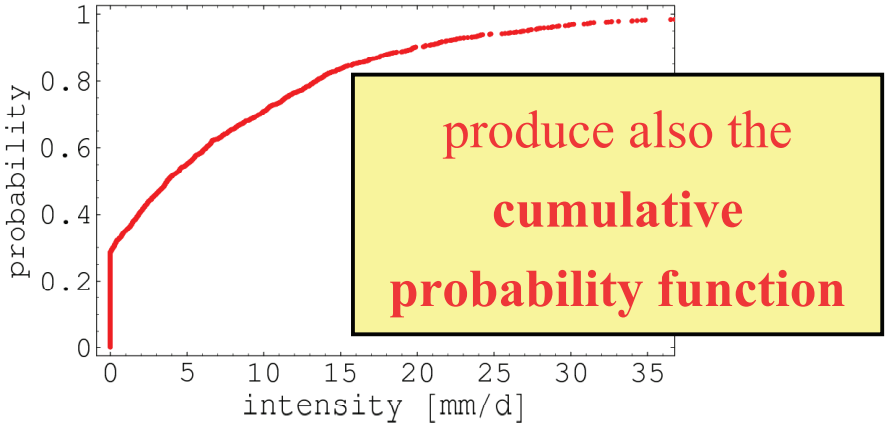
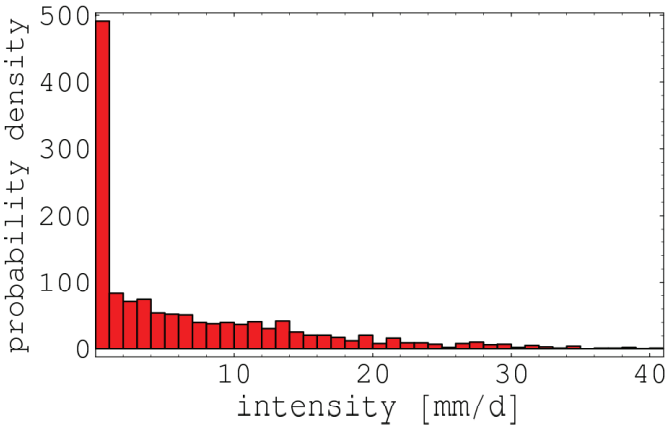
Observed and modeled time series

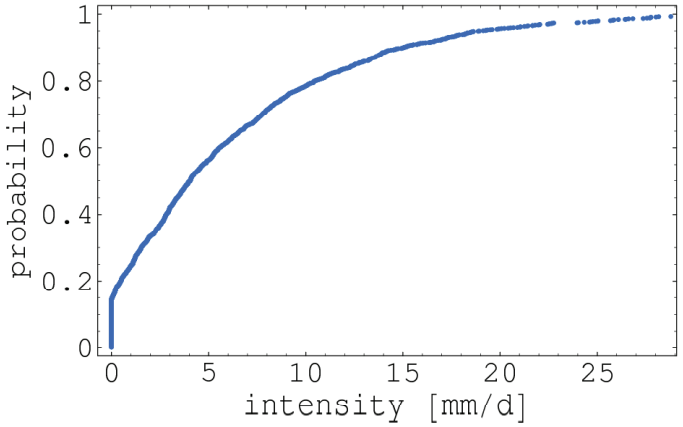
observed

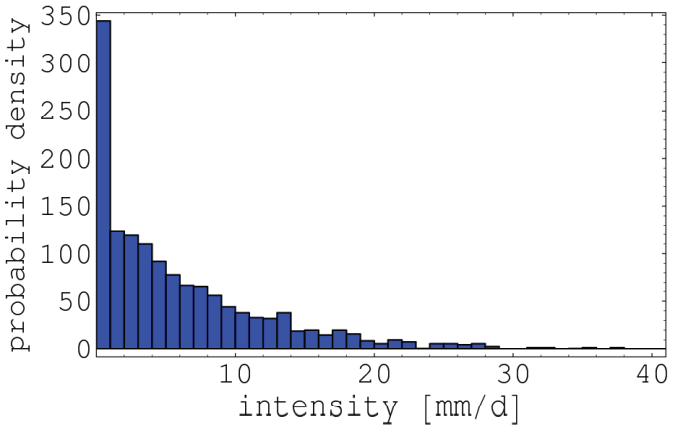


produce also the **cumulative probability function**



modeled





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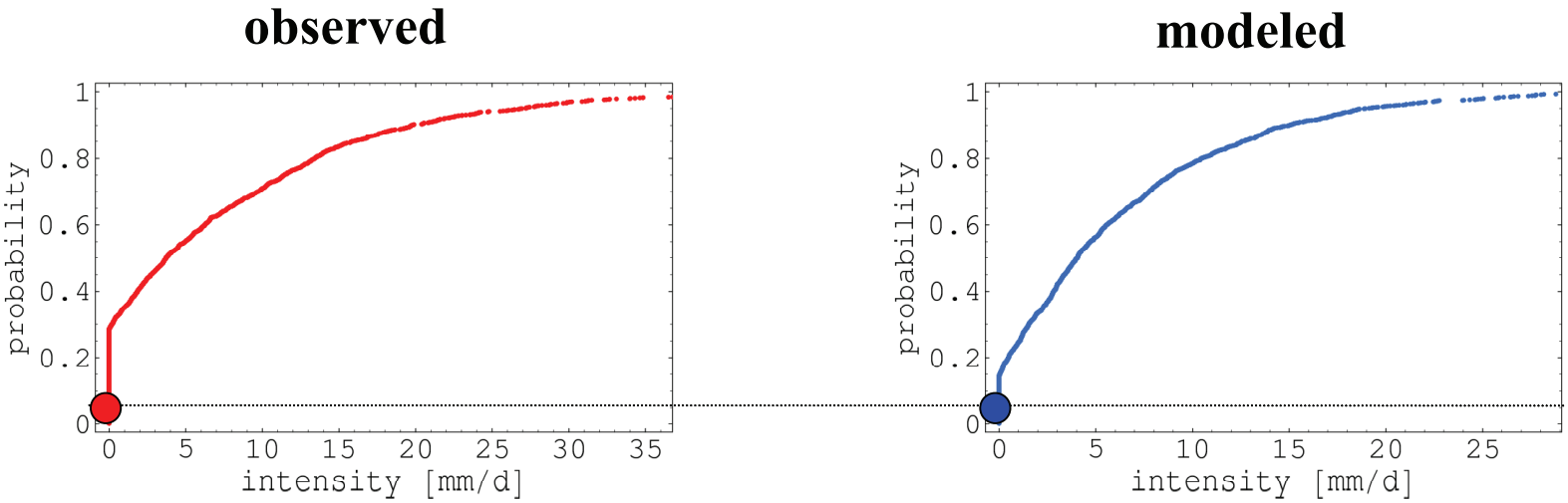
Observed and modeled time series

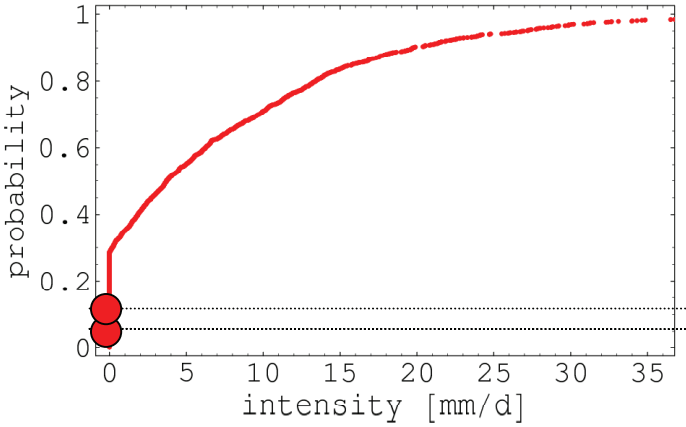


- probability mapping defines a

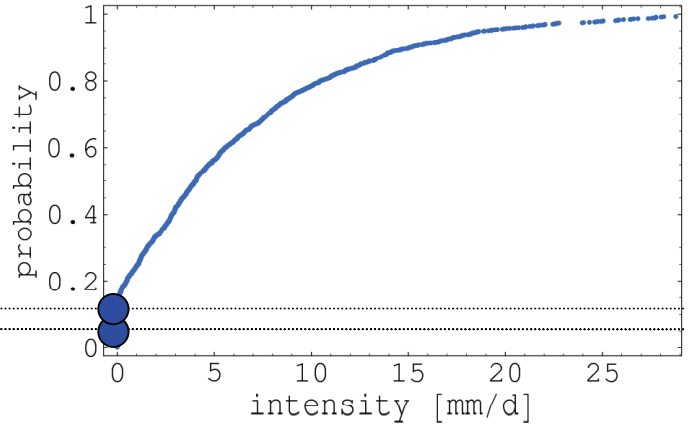
  transform function

Observed and modeled time series

observed

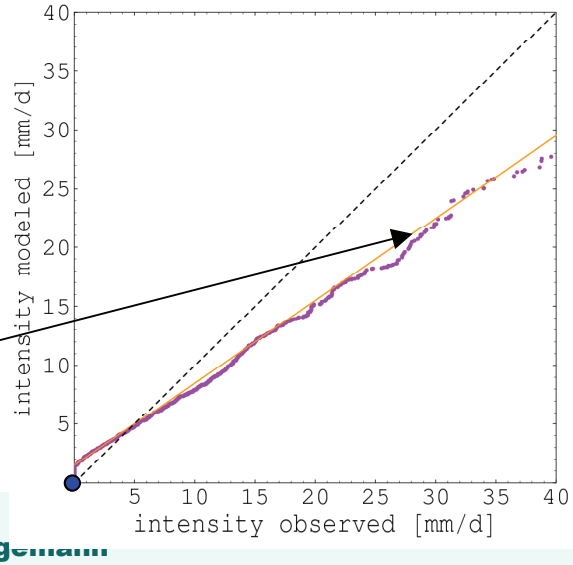


modeled

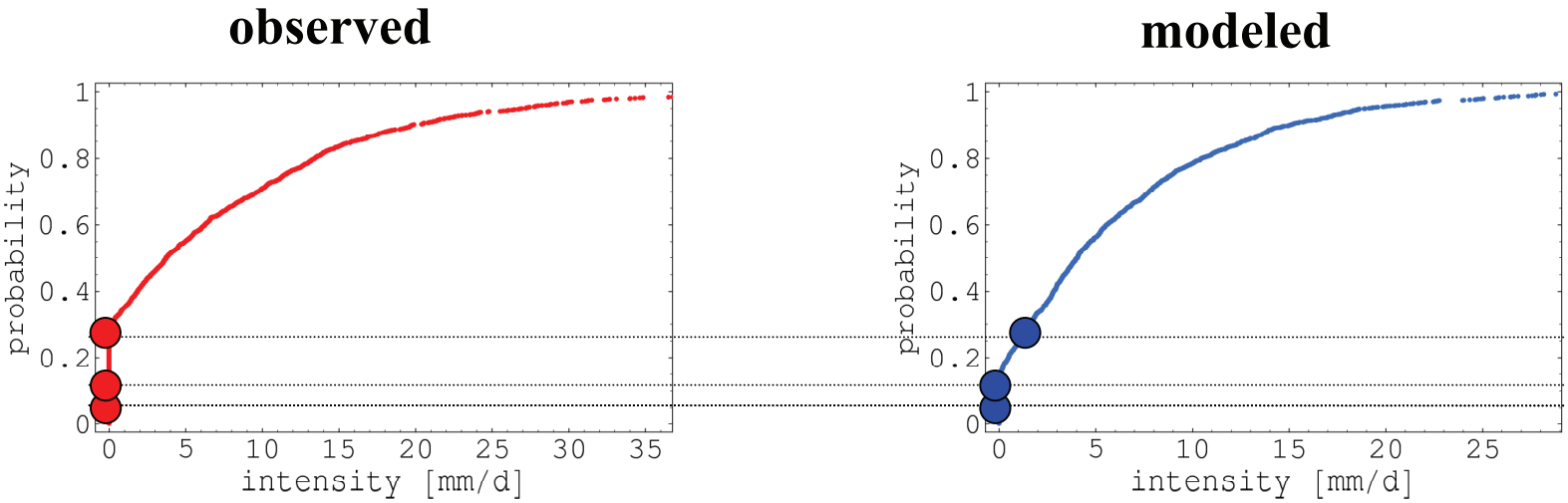


- probability mapping defines a **transform function**

orange: 2-parameter fit to transform function



Observed and modeled time series



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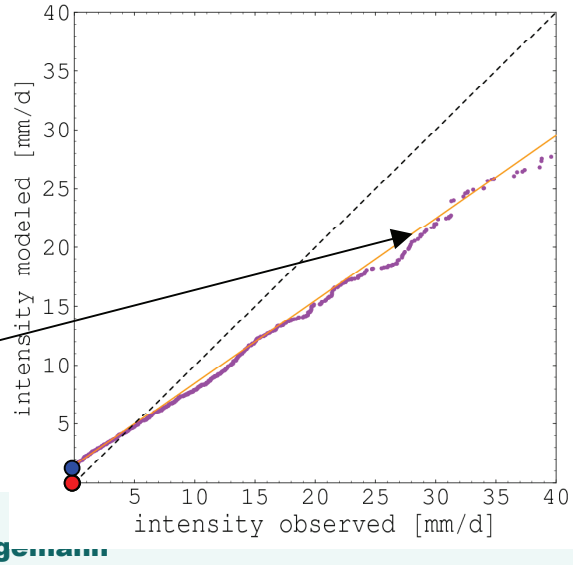
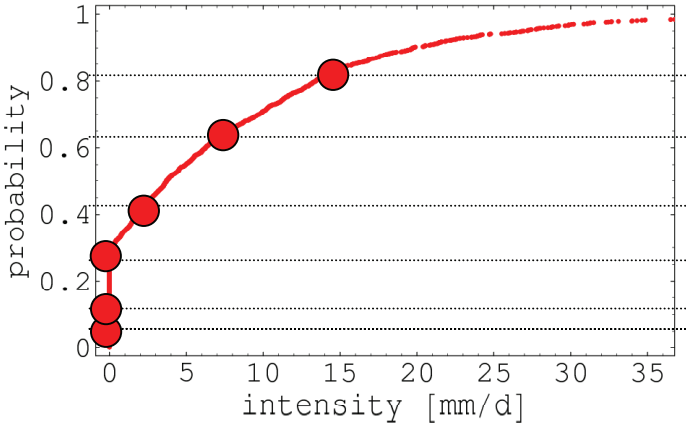
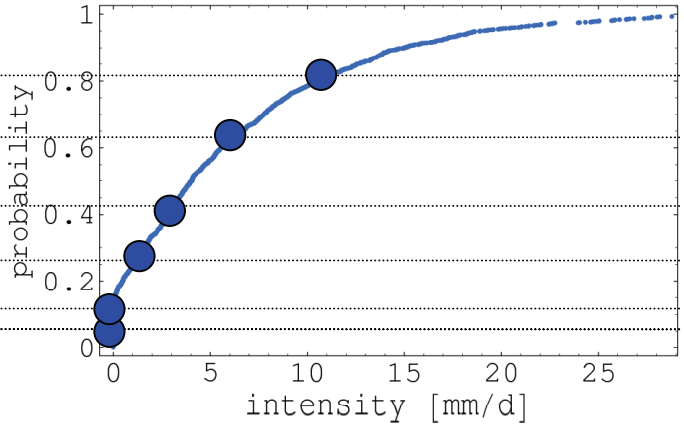


Observed and modeled time series

observed



modeled



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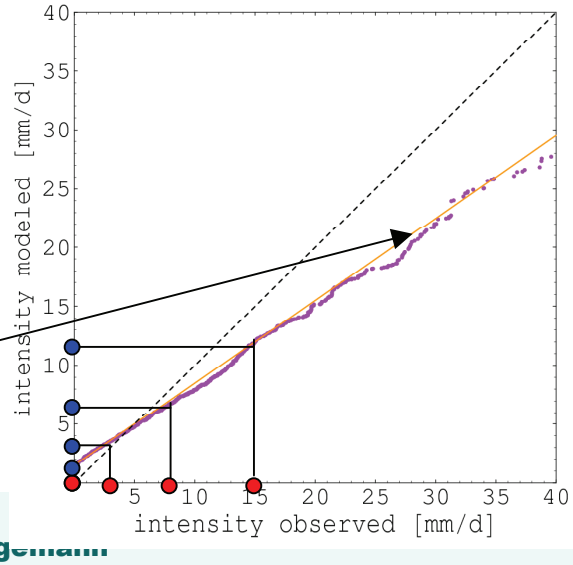
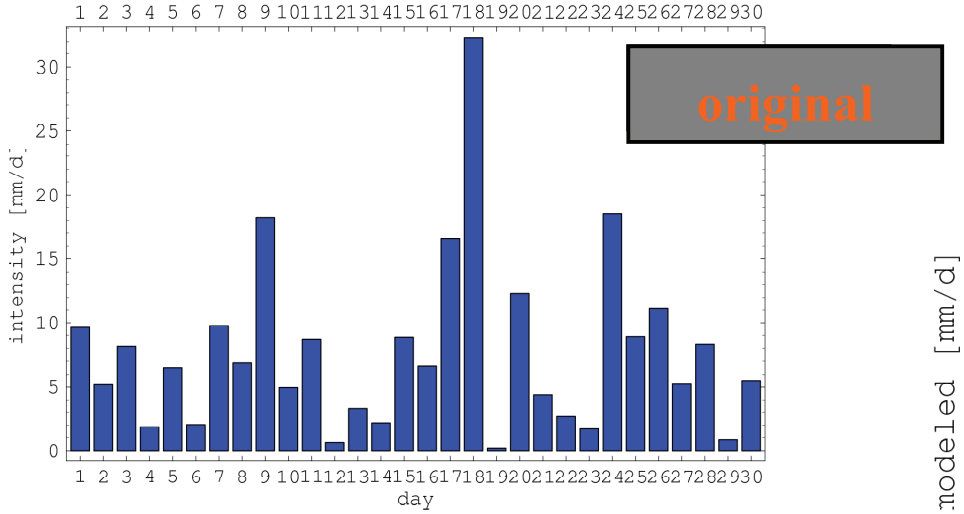
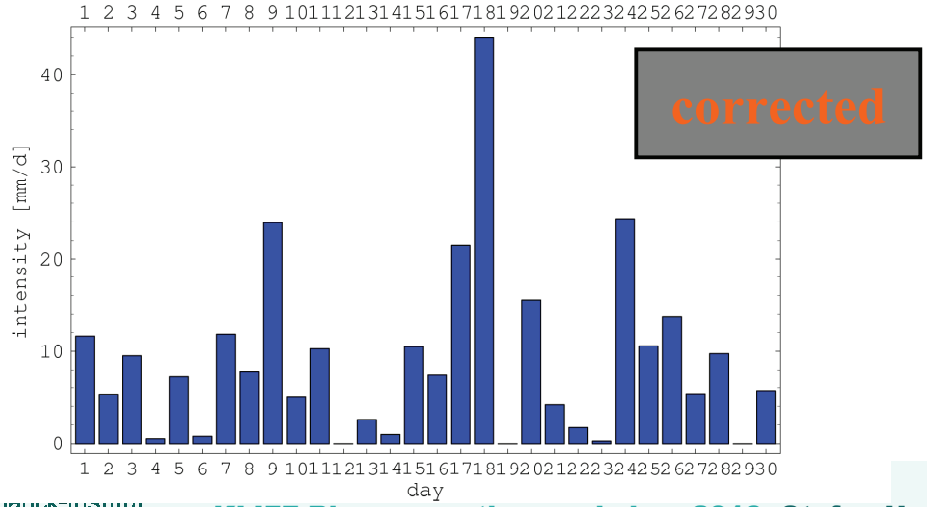


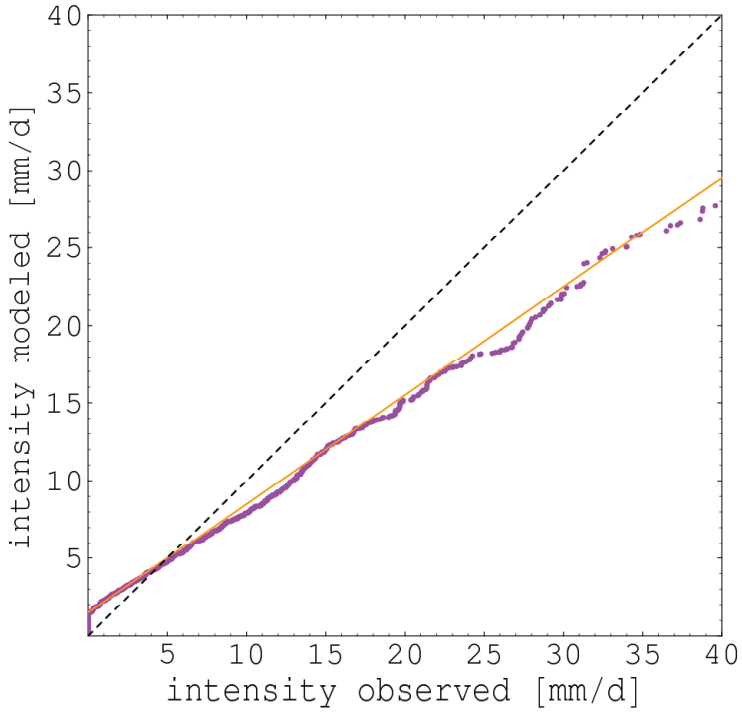
orange: 2-parameter fit to transform function

Observed and modeled time series

modeled

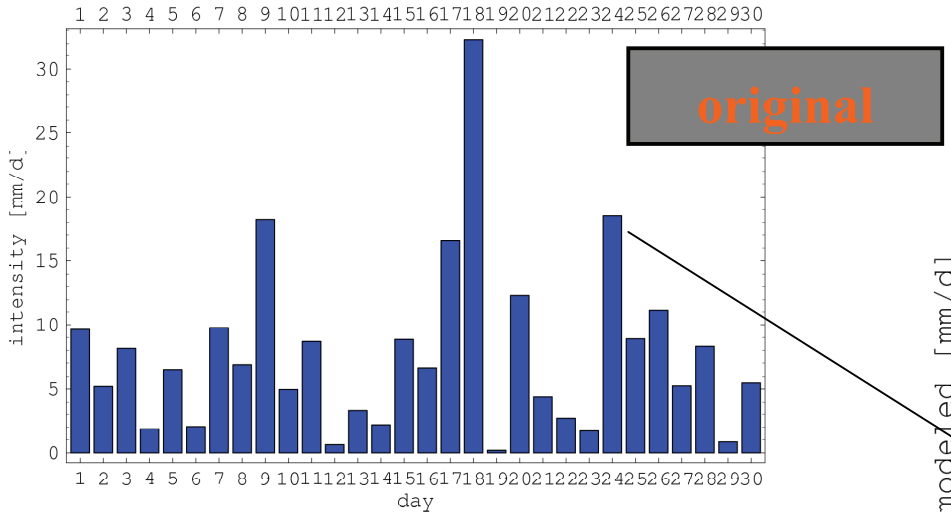


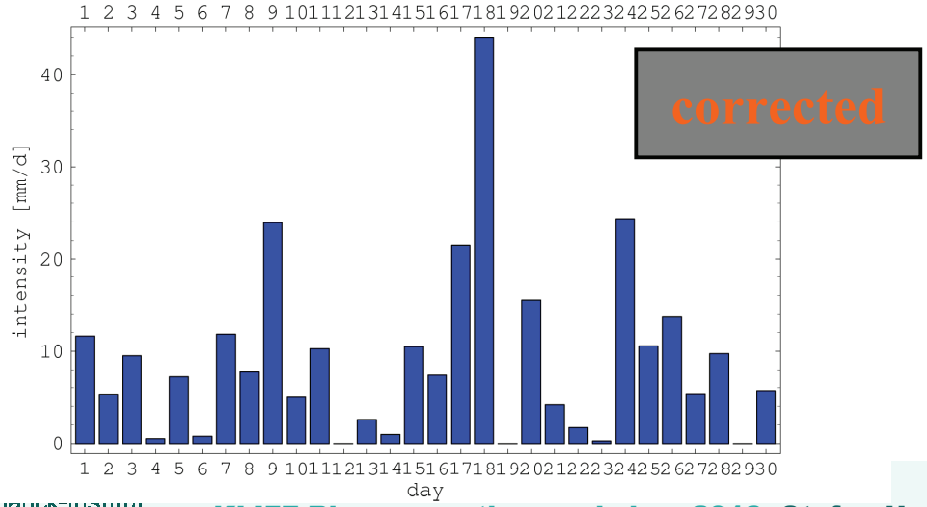


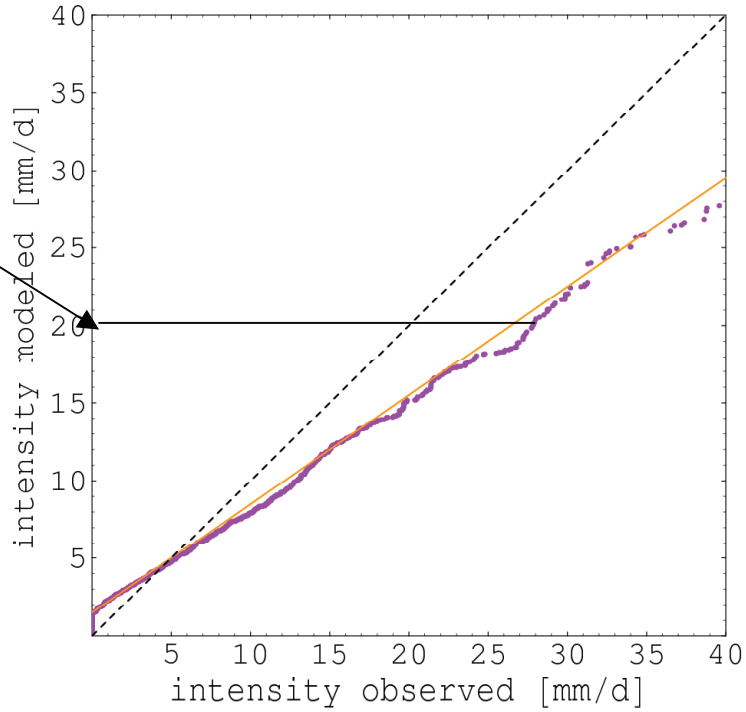


Observed and modeled time series

modeled

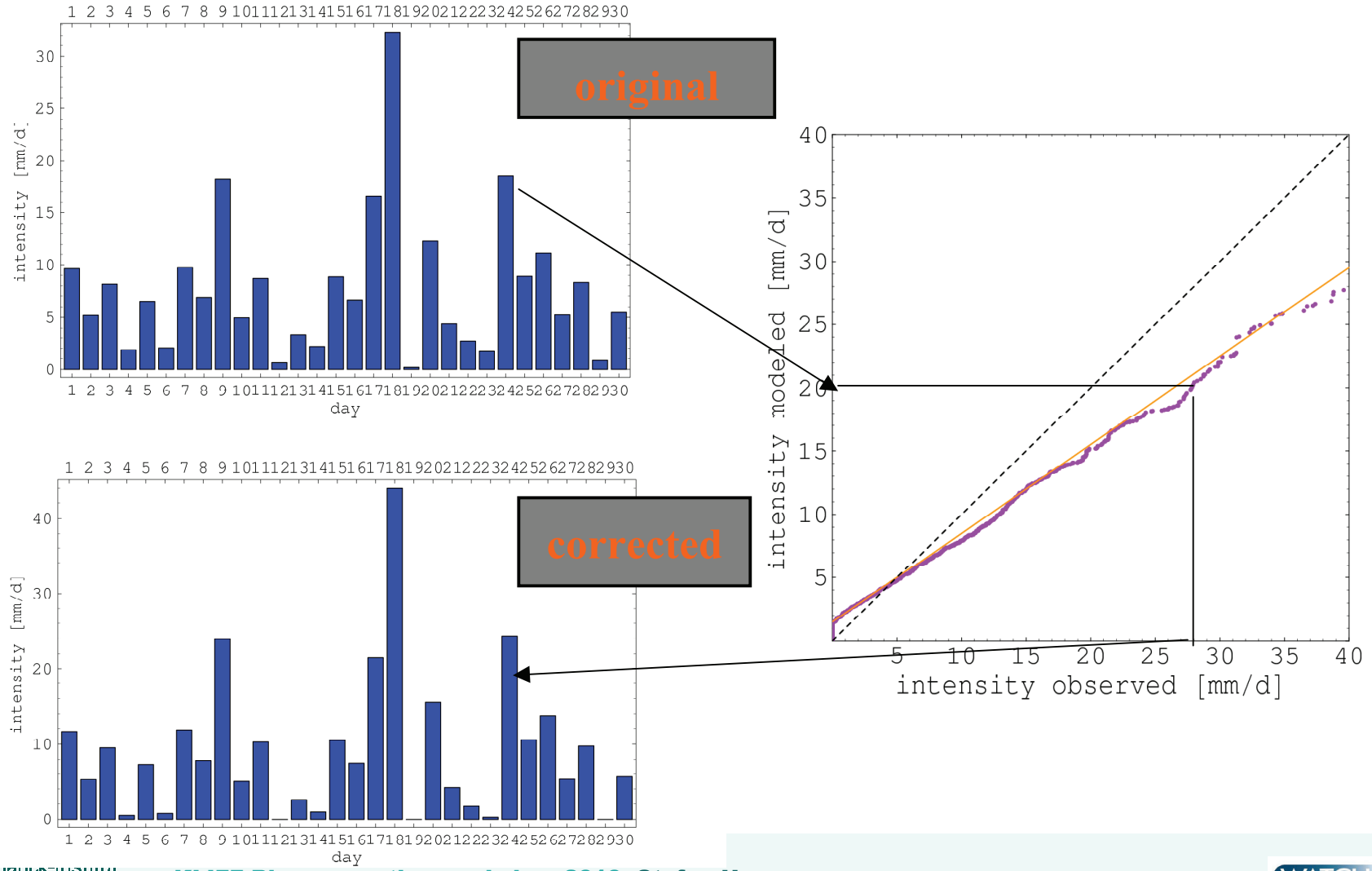






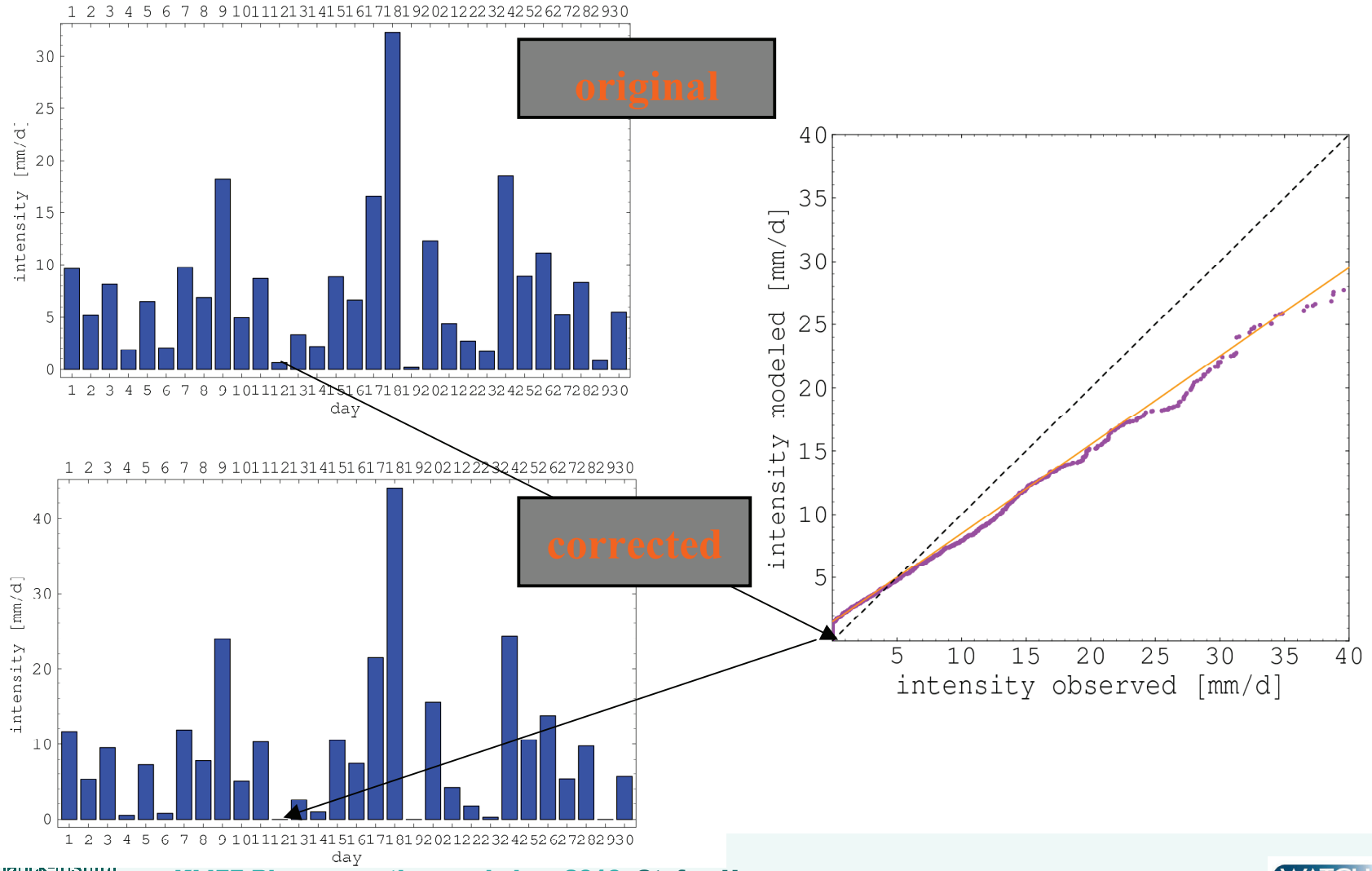
Observed and modeled time series

modeled



Observed and modeled time series

modeled



Summary of methodology

- In theory: bias correction **adjusts all moments** of distribution function for each day.
- In practice: For most regions, a **2-parameter fit** to the **transform function** is used as a **good approximation**.
- Specific regions use 3 or 4 parameter transfer functions.
- Using larger number of parameters may not be adequate as correction needs to be **time-independent on climatological time-scales** (>10 years).
- Similar procedure has been followed for temperature correction (always 2-parameter fit).
- Monthly transfer functions will be used, with smooth transitions for temperature.

Data

Observations: Daily WATCH forcing data (Weedon et al. 2010)

- ERA40 data interpolated to 0.5° with elevation correction to CRU
- 2m temperature: Correction with monthly means CRU data.
- Precipitation: Correction with monthly GPCC Vs.4 data, and a gauge-undercatch correction according to Jennifer Adam.

Daily GCM Model data: ECHAM5/MPIOM at T63L31 ~ 200 km

- Interpolated to 0.5°
- 1. Derive bias correction factors for 1960-69, apply to 1990-99
- 2. Derive and apply bias correction factors to 1960-99

- Precipitation, (Snowfall fraction taken from GCM)
- Temperature: T_{mean}, T_{min}, T_{max}
  - Diurnal Range: $\Delta T = T_{max} - T_{min}$
  - Skewness: $\sigma = (T_{mean} - T_{min}) / \Delta T$

Transfer functions

The bias correction equations

$$x_{cor} = a + bx$$

Linear approximation to transfer function: 2 parameters

$$ln\ (x_{cor}) = a + bln(x - x_0)$$

Logarithmic fit: 3 parameters

$$x_{cor} = (a + bx)(1 - e^{(-(x-x_0)/\tau)})$$

$$x_{obs} = x_{obs}\ (\varphi\ ,\theta\ ,d,m,y)$$

Exponential with an asymptote: 4 parameters

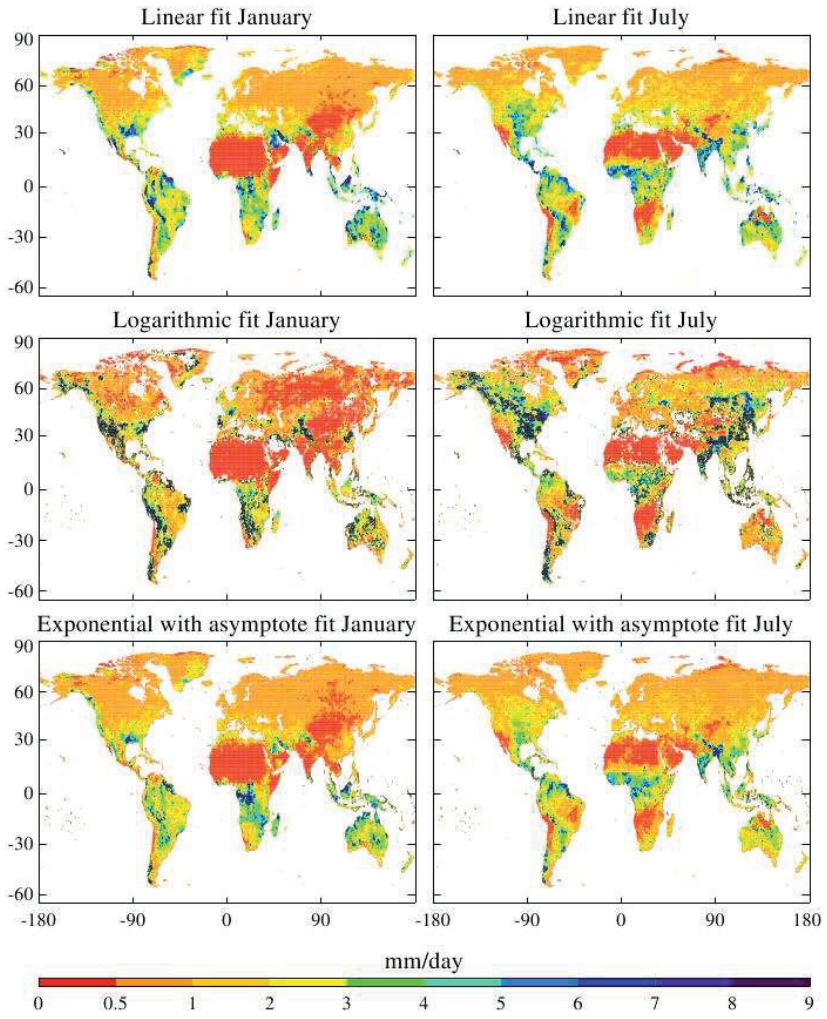
Transfer functions

Fitting Error
RMS error of the fitted function to the emerging perfect TF

Linear fit

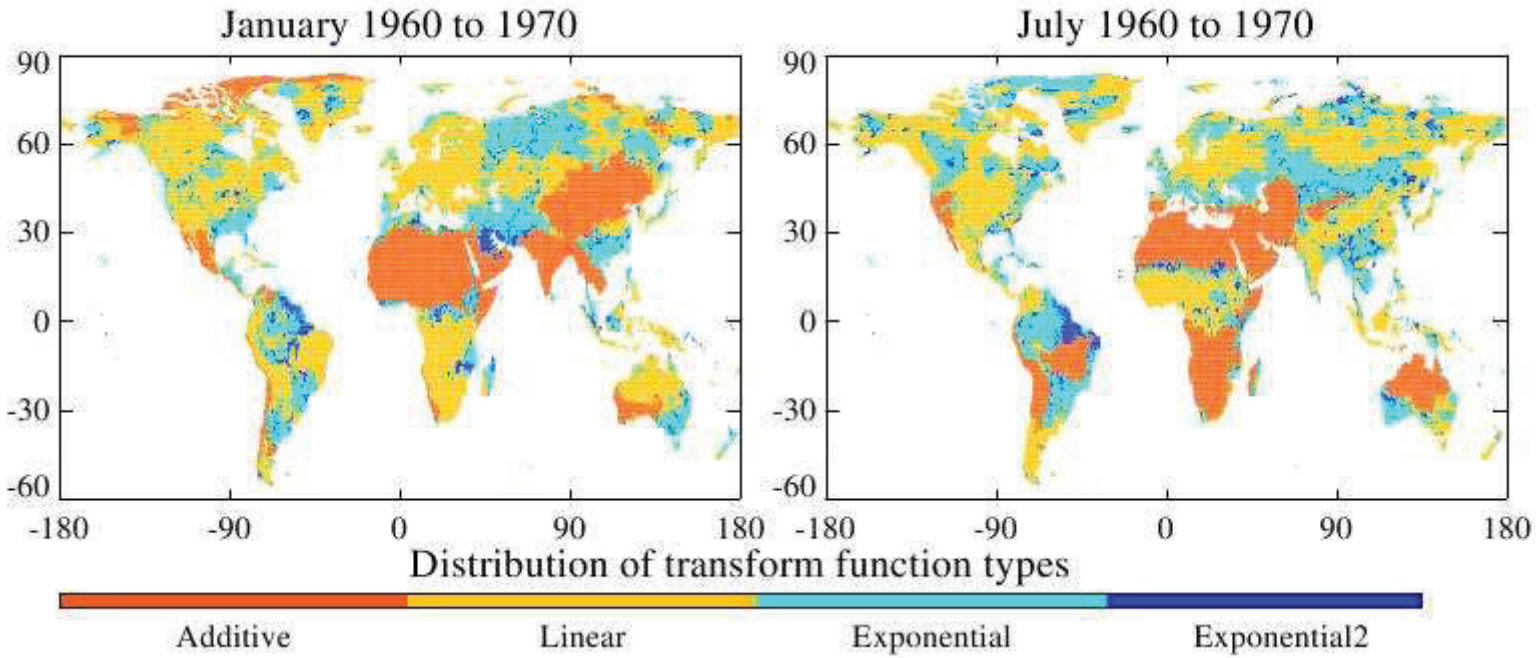
Logarithmic fit

Exponential with asymptote



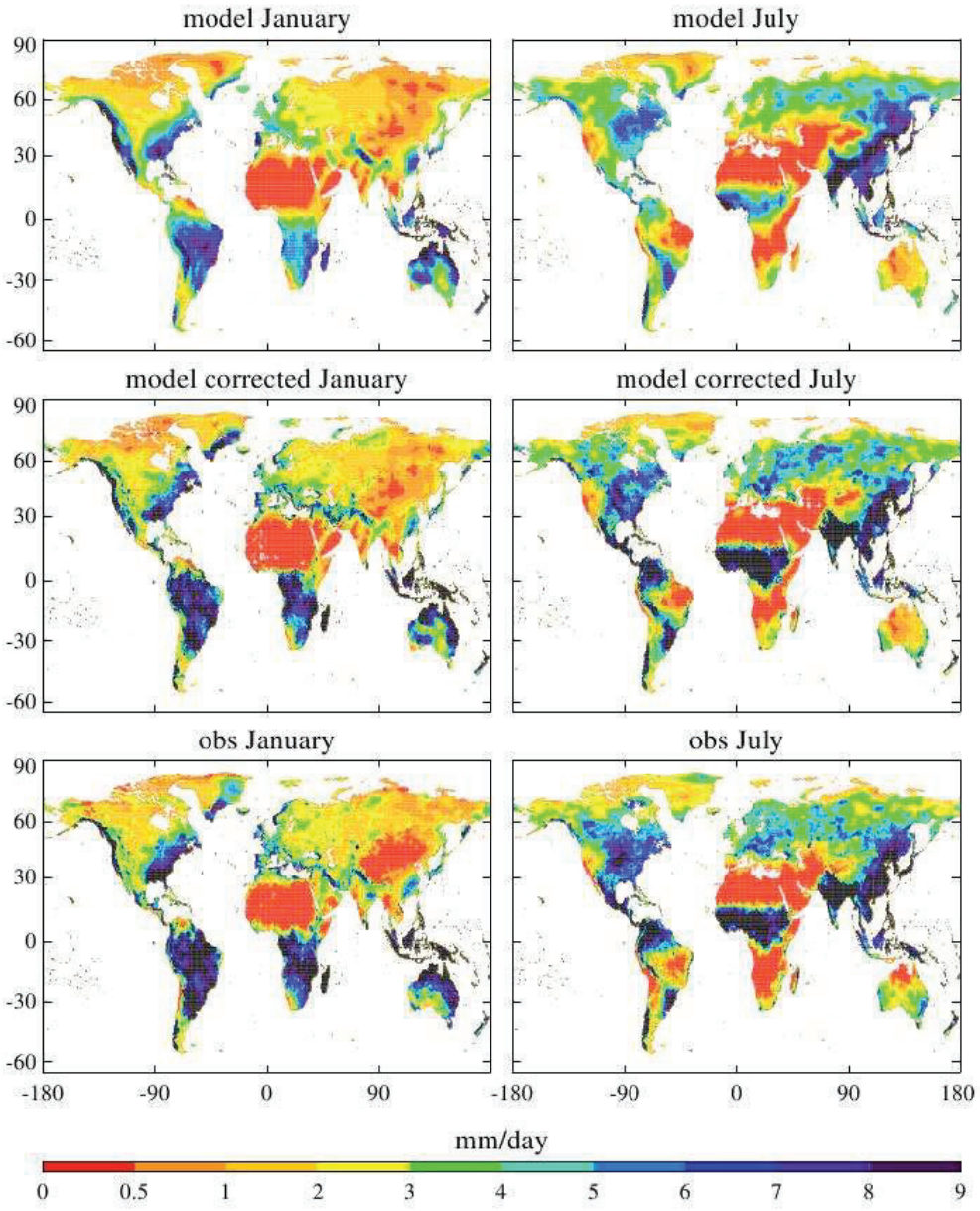
Transfer functions

- Spatial distribution of the choice of transfer function type
- Mostly linear TF used (yellow)
- additive TF is only option in very dry regions (orange)



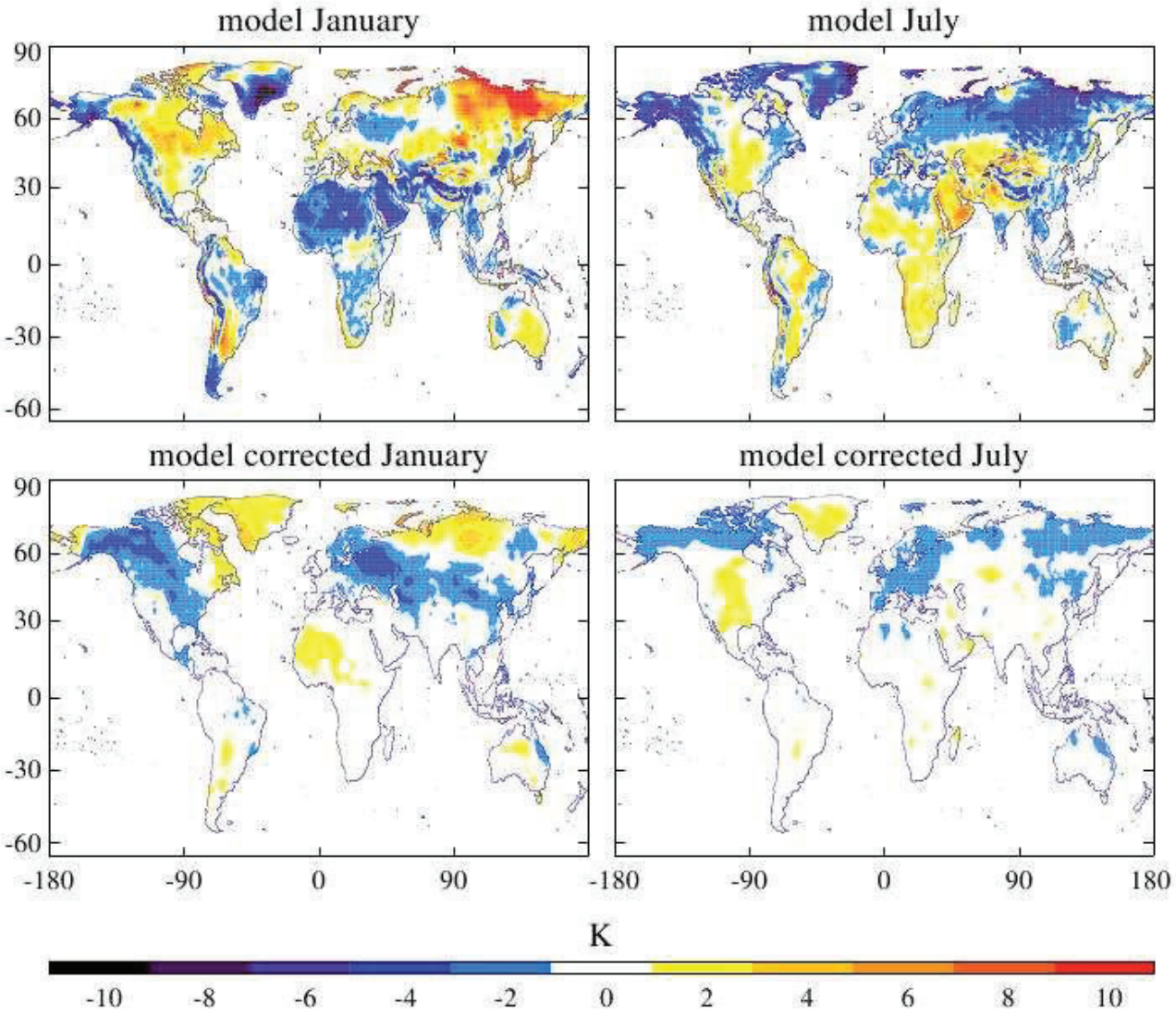
Standard Deviation of Precipitation

Clear improvement for mean daily precipitation (not shown) as well as for the **Standard deviation of monthly precipitation**



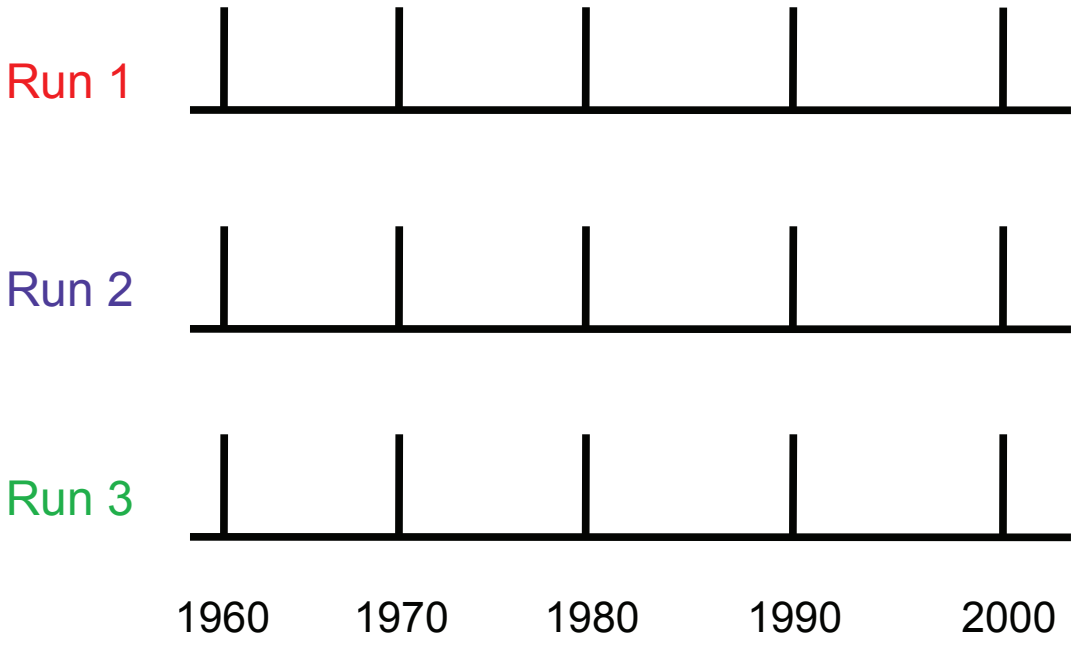
Temperature difference to observations (WFD)

Clear improvement for **mean daily temperature** and its standard deviation (not shown)



Robustness of method

Assessing fluctuation of BC parameters
within 12 decades (4 decades x 3 ECHAM runs)



12 BC parameter sets

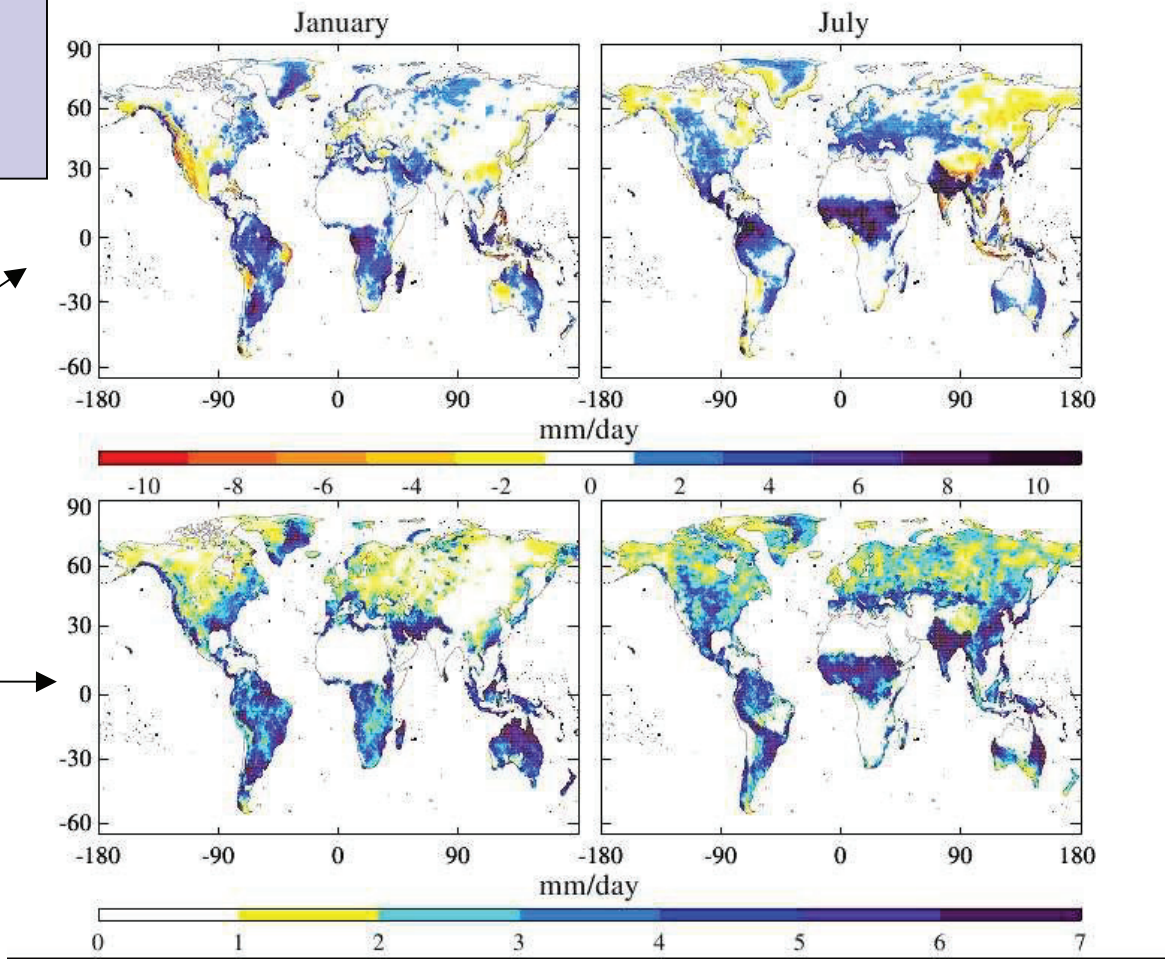
Construct mean and standard deviation of corrections

Robustness of method

Uncertainty
Impact of parameter fluctuations on extremes

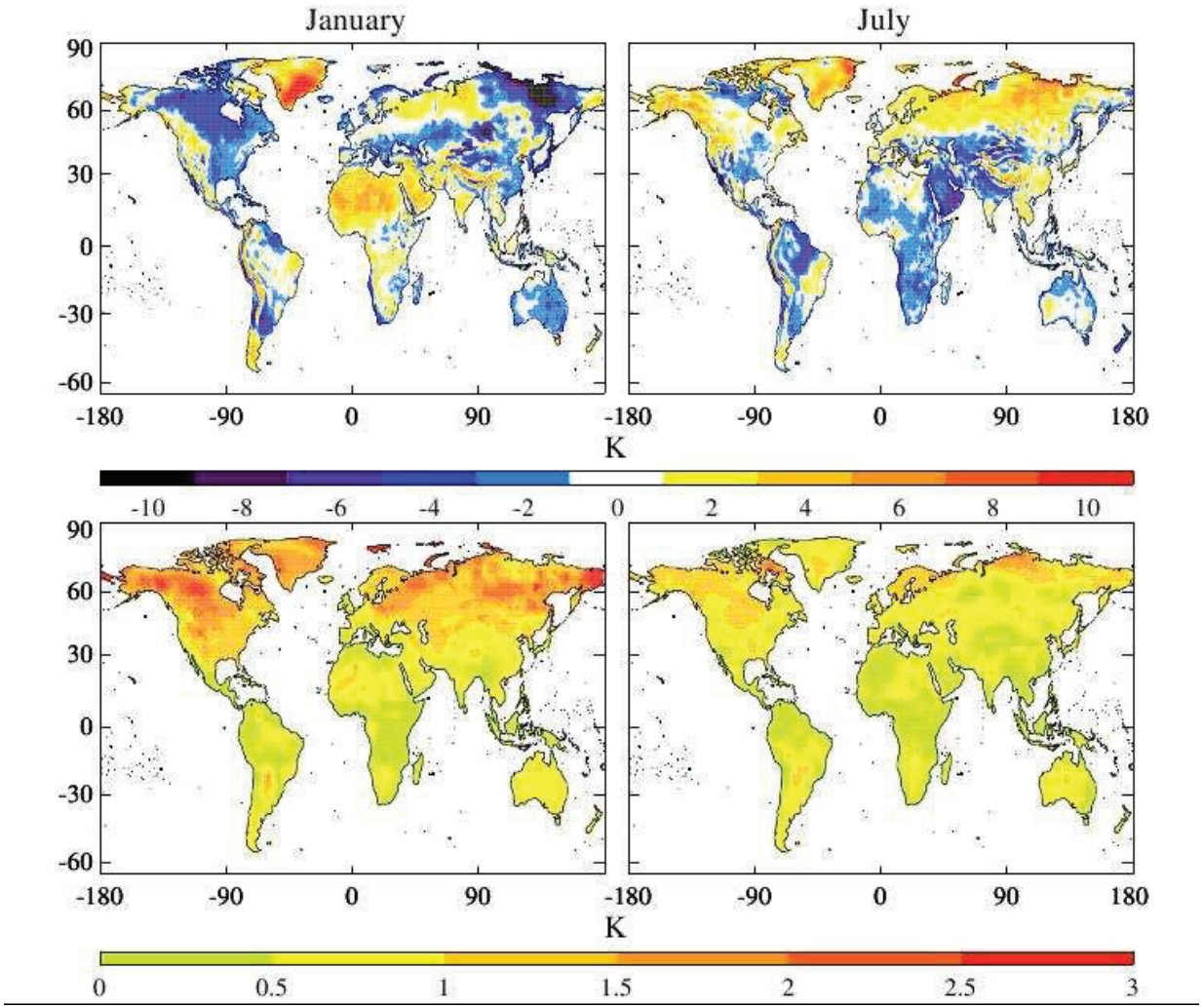
Average additive correction for 90th percentile

Standard deviation across 12 corrections for 90th percentile



Robustness of method

Uncertainty
Extremes of daily mean temperature

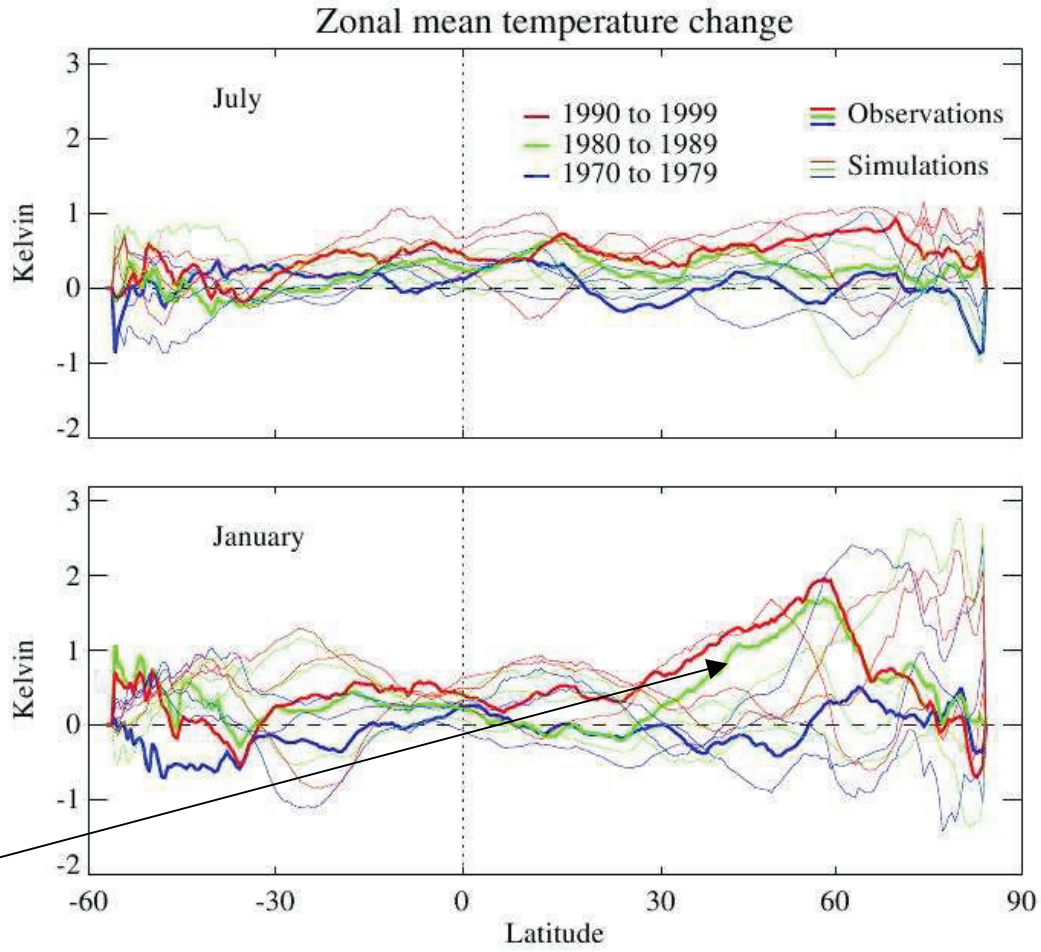


Robustness of method

Uncertainty
Zonal mean temperature change

Bold lines = observations

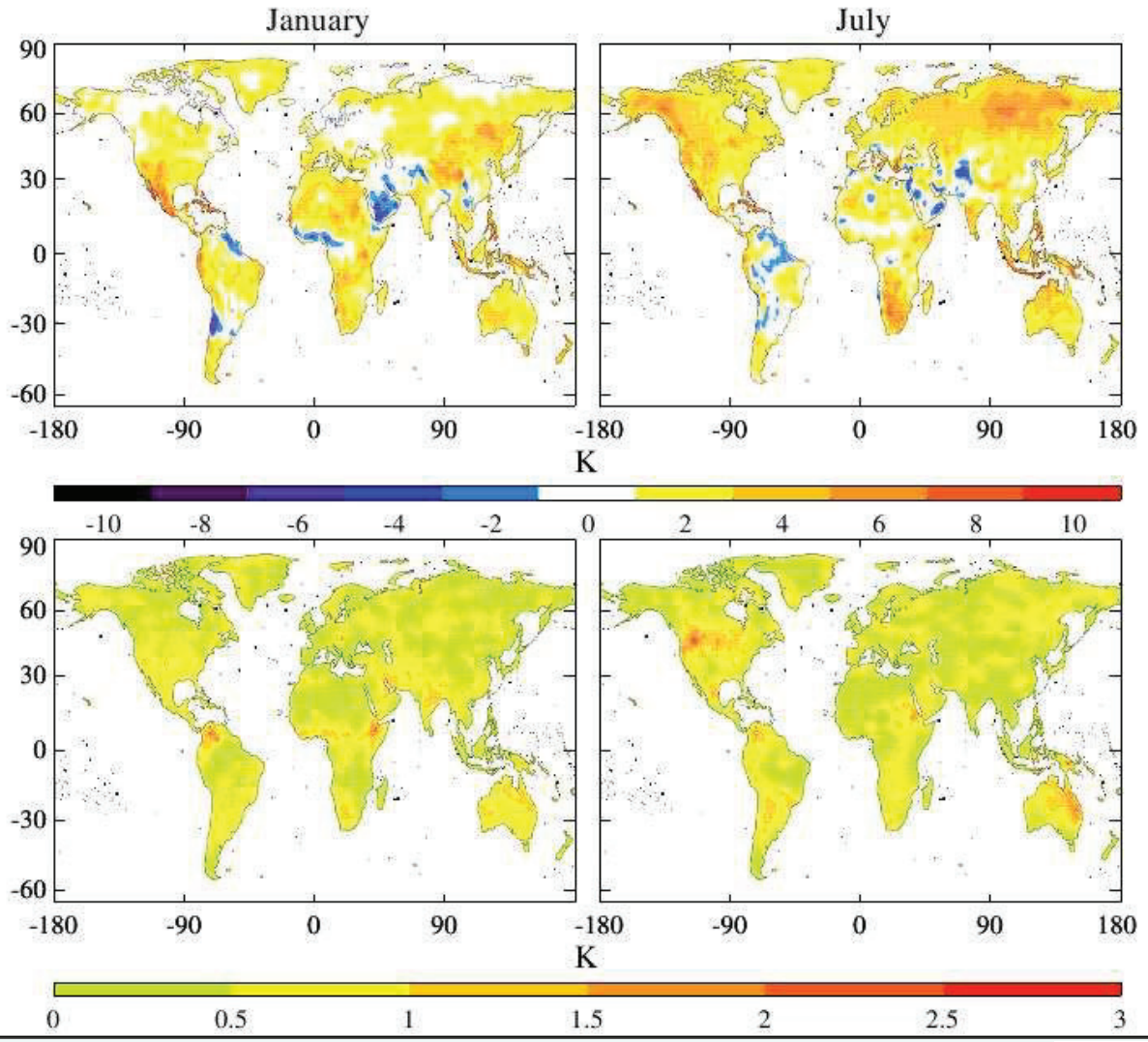
skinny lines = model



- Natural variability responsible for large part of standard deviation in correction

Robustness of method

Uncertainty
Daily Temperature Cycle



Summary I

- Application of statistical bias correction to ECHAM5 data has shown that it effectively improves both the mean and the variance of the precipitation and temperature fields in all but a few regions of the globe.

- For precipitation, it can also correct higher moments of the distribution.

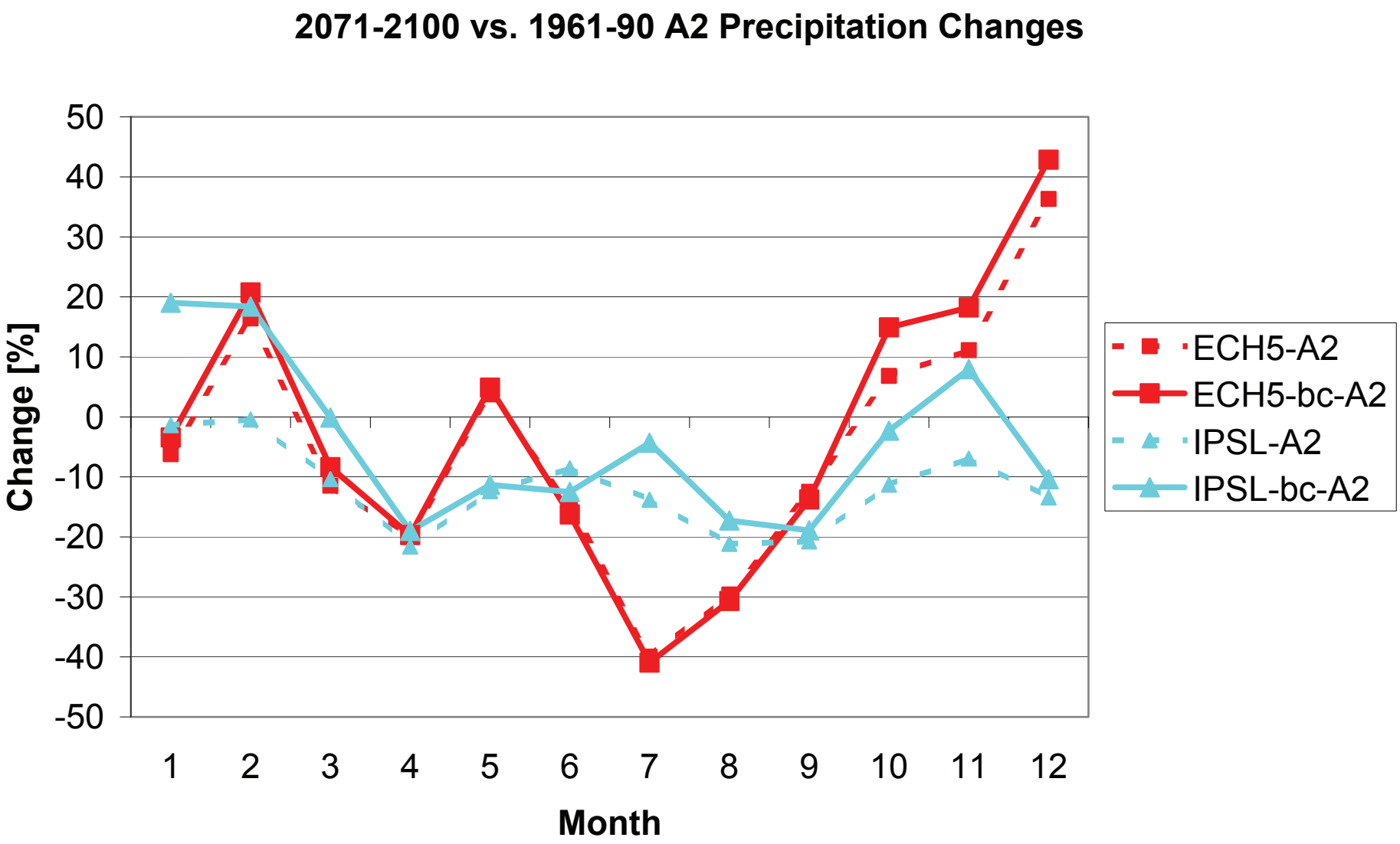
- Methodology test: Deriving the correction factors for 1960-1970 and applying it to 1990-2000, thereby mimicing the unfavorable condition of correcting a future scenario simulation.

Summary II

Robustness using all 4 decades of 3-member ensemble runs (different initial conditions):

- Larger uncertainties occur in regions where larger corrections are applied to the high intensity precipitation events, for temperature this is not the case
- Part of the uncertainty in bias correction parameters is associated with the inter-decadal variability which differs between model runs and between models and 'observations'
- Robustness is likely to be improved when more than 10 years are used to compute the bias correction parameters, e. g. by using a 30-40 year period, where inter-decadal variability should be greatly reduced
- It would always be useful to use a multi-member initial condition ensemble to at least reduce the inter-decadal variability of the model statistics. In this way all ensemble members for the first period (say 1960-1970) could be used to construct the correction factors and all three members for the second period (1990-2000) could be used to test the correction.

Climate change signal for Danube



Summary III

- Bias correction has an impact on the climate change signal for specific locations and months
- Possible explanation for these cases
  - Low precipitation amounts (or temperatures) are differently corrected as high amounts (due to different model biases)
  - If distribution between low and high amounts changes in a future climate, bias correction may lead to changes in the analysed signal.
  - This will be analysed further in more detail.

Planned common WATCH special issue publication

Hagemann, S., C. Chen, J.O. Haerter, D. Gerten, J. Heinke and C. Piani

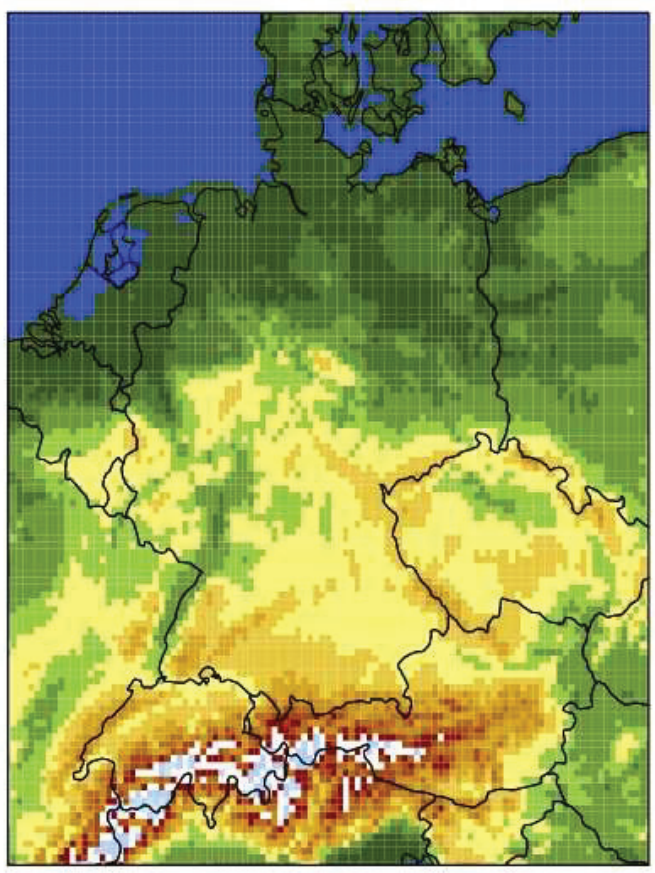
Usage of a global statistical bias correction to enhance simulations of the current and future hydrological cycle

- Application of bias correction to ECHAM5, CNRM-CM3 and LMDZ-4 data and forcing of MPI-HM and LPJ.
- Impact of bias correction on climate change signal
  - Precipitation and temperature from the GCM
  - Evaporation, Soil moisture, River runoff from the Hydrology Model

Erstellung eines bias-korrigierten Datensatzes für Deutschland

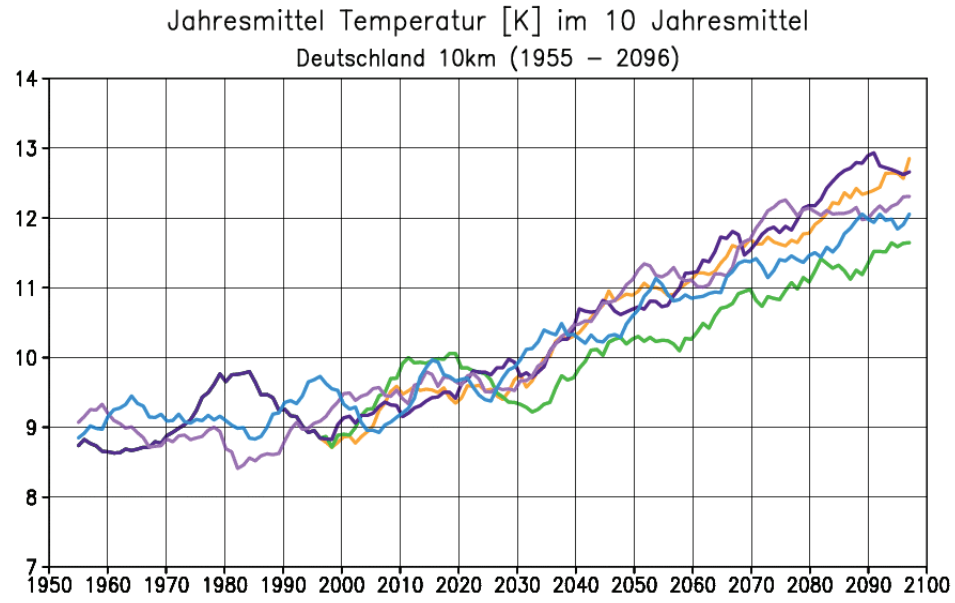
Nach der Methode in Piani *et al.* (2009), Piani *et al.* (2010)

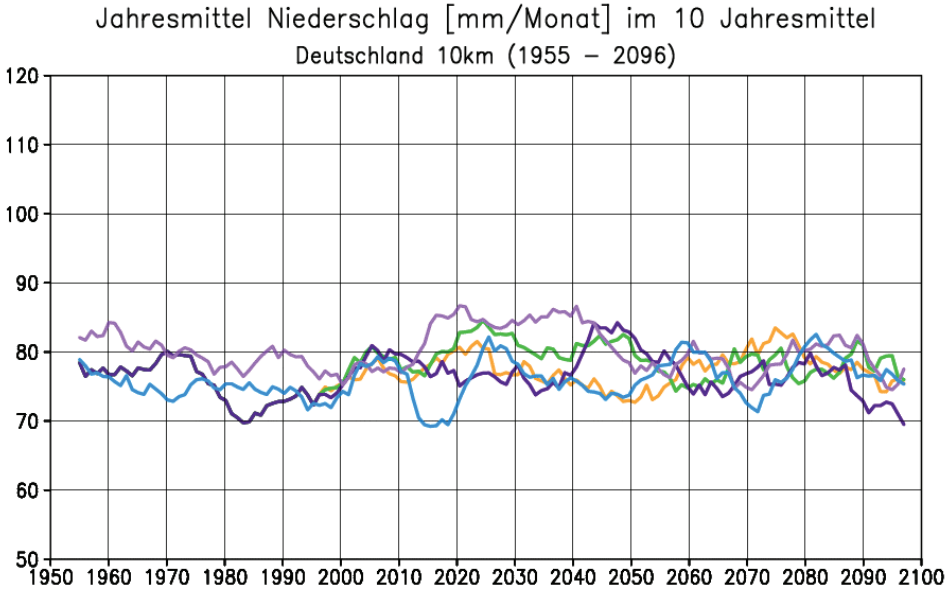
REMO Modellensemble



Simulationsgebiet

- Räumliche Auflösung: 10×10 km auf rotiertem Gitter
- Zeitliche Auflösung: stündlich (Biaskorrektur: täglich)
- Antrieb an den Rändern mit dem Globalmodell ECHAM5-MPIOM





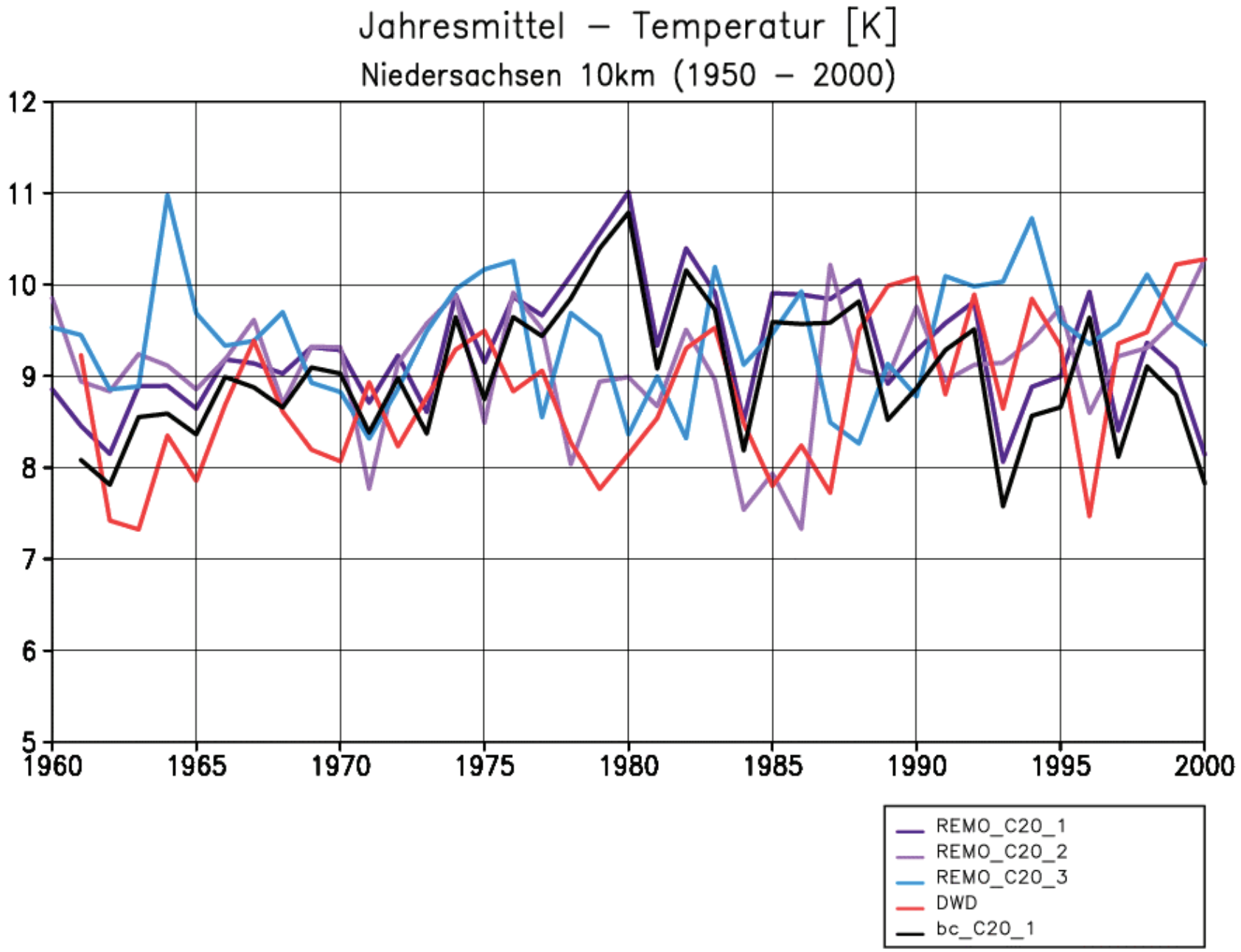
C20_1_A1B_1-UBA
C20_2_A1B_1-BFG
C20_3_A1B_1-KLIMZUG
A2_1
B2_1

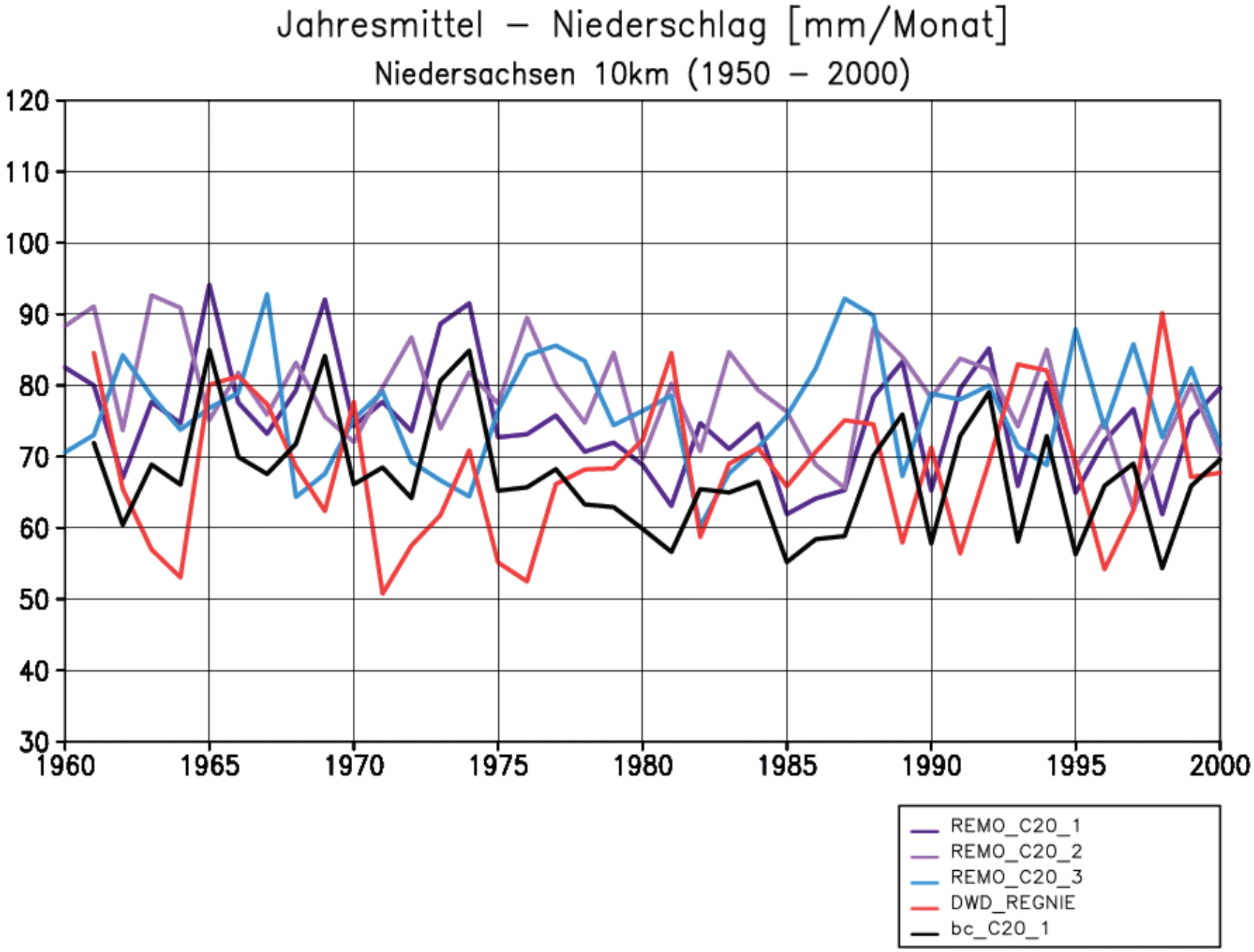
Statistische Biaskorrektur

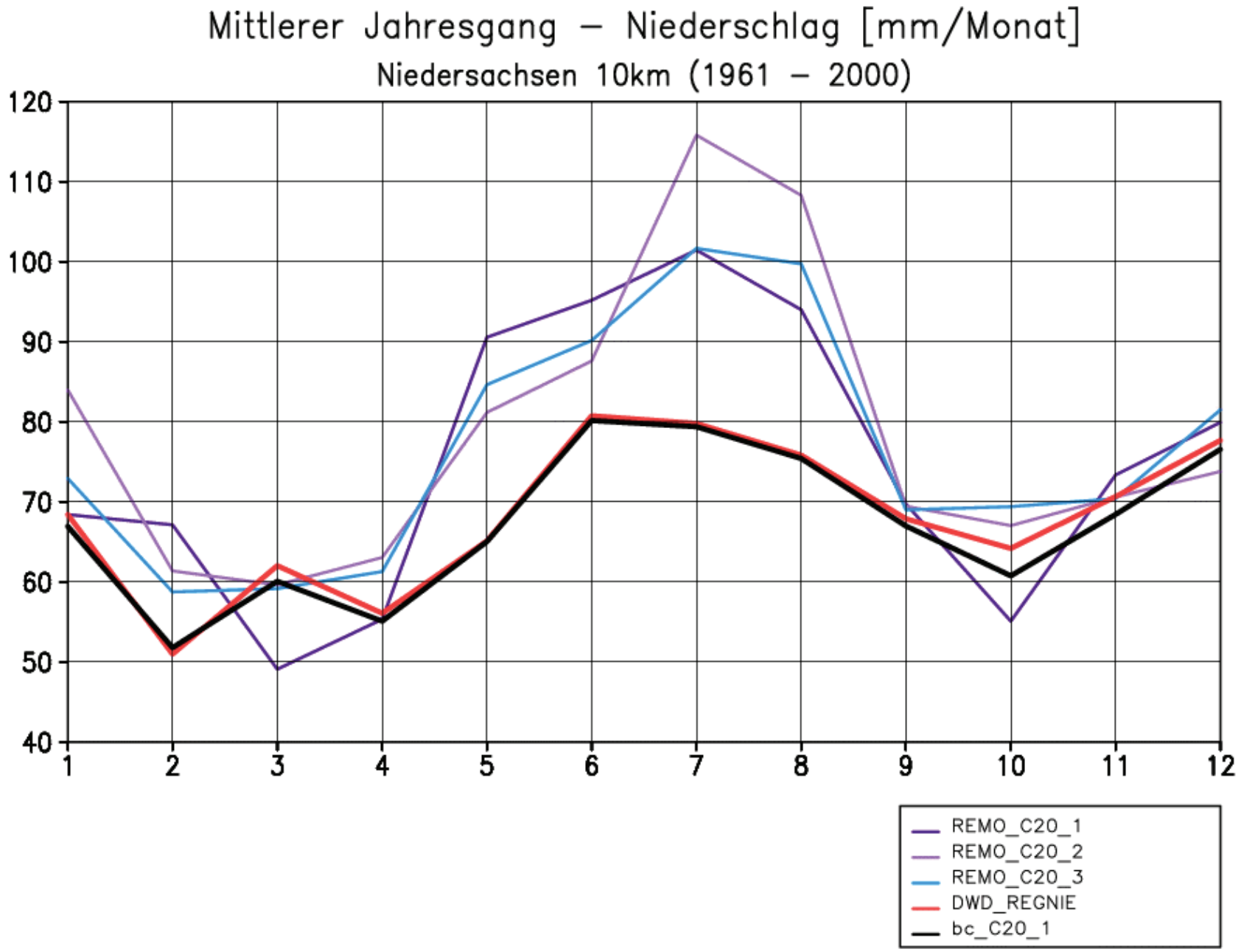
Input-Datensatz	Zeitraum	Klimavariable
REMO-UBA, A1B_1 Szenario	1961-2100	TEMP2, T2MIN, T2MAX, DPREC
ECA(*), interpoliert von 25 auf 10 km	1961-2000	TEMP2, T2MIN, T2MAX
REGNIE (DWD)	1961-2000	DPREC

(*) Haylock *et al.*, *J. of Geophysical Research* 113, D20119 (2008)

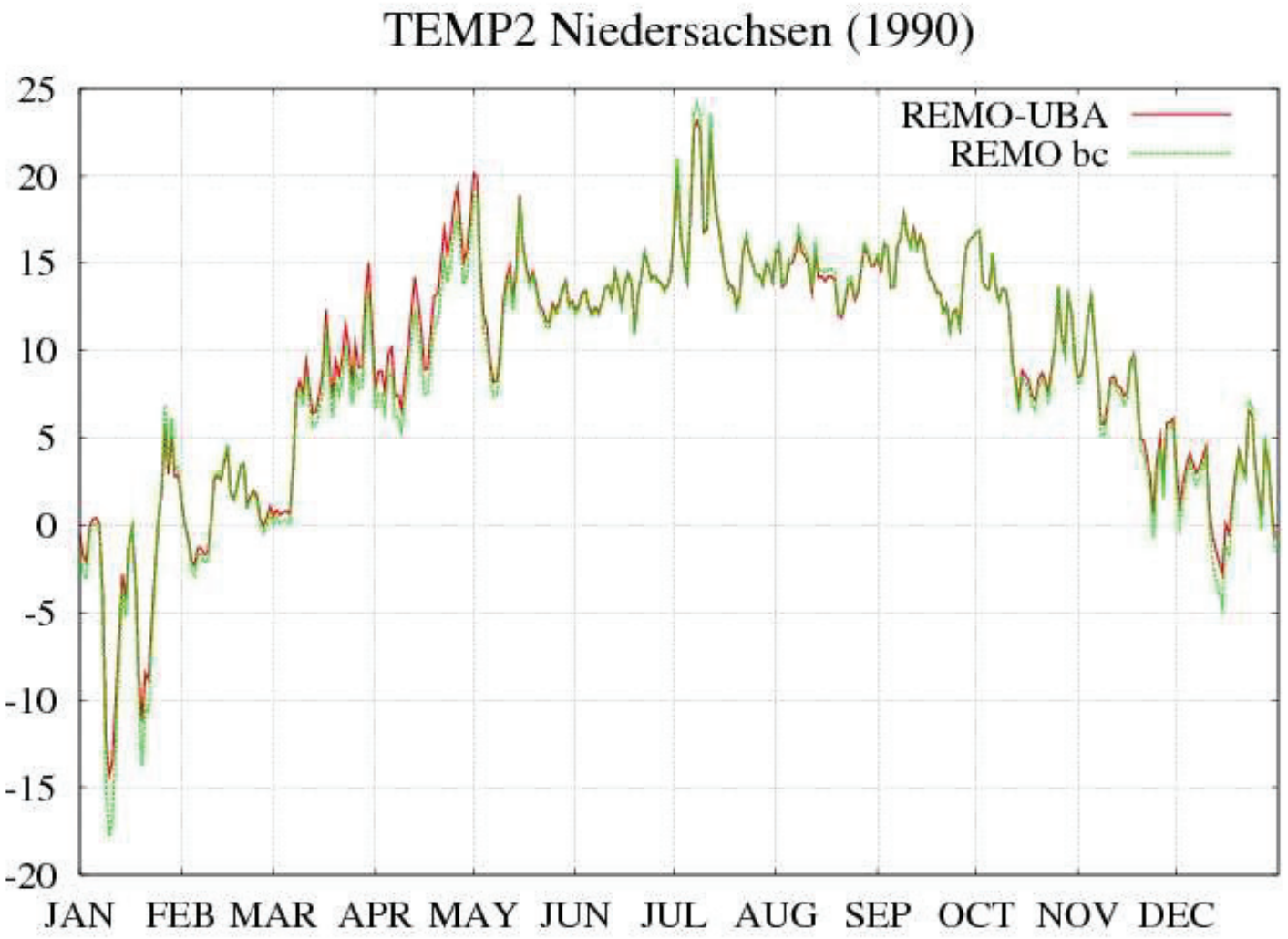
Einfluss der Bias-Korrektur auf den Kontrollzeitraum

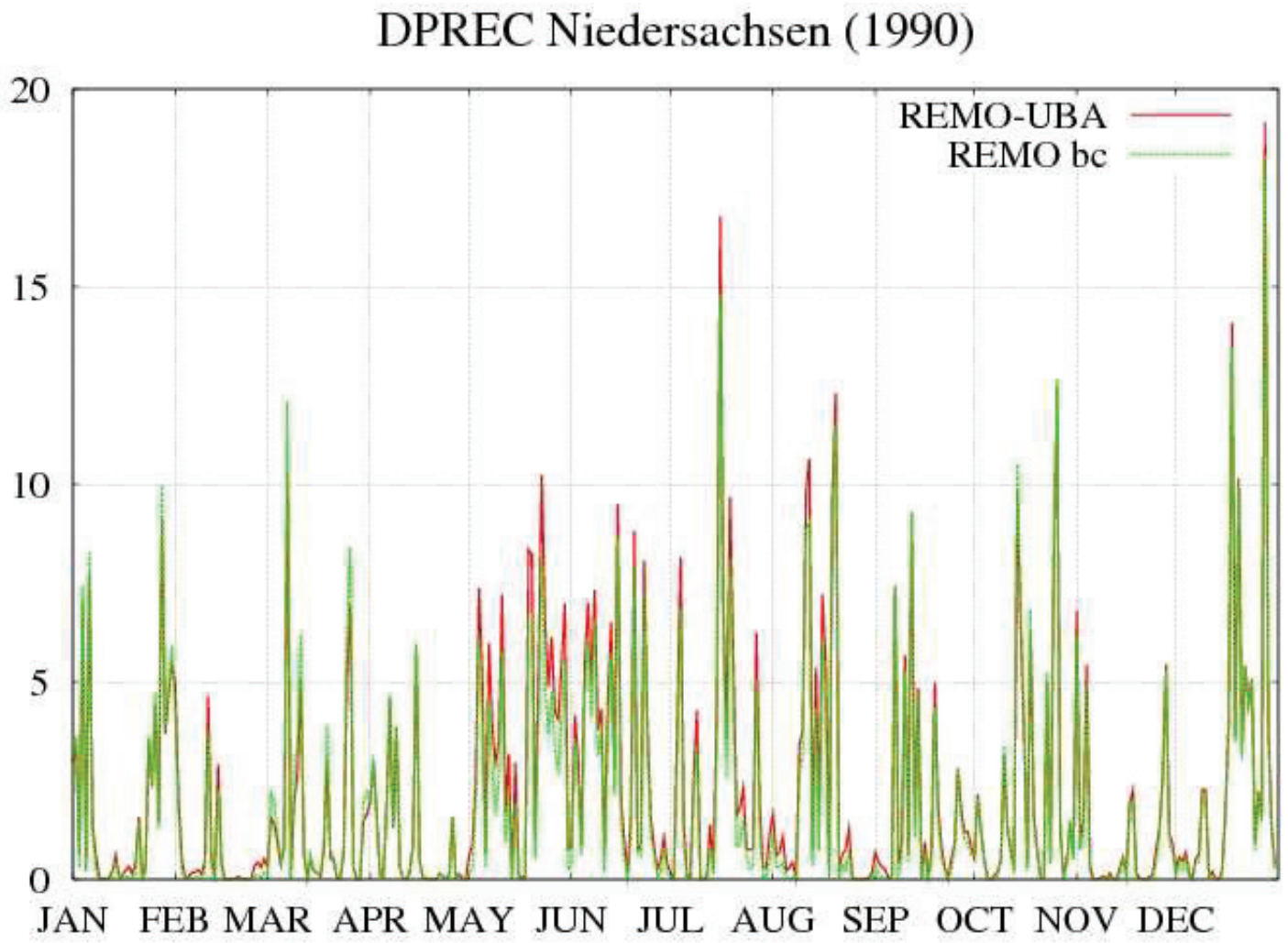

Jahresmittel – Temperatur [K]
Niedersachsen 10km (1950 – 2000)
12
11
10
9
8
7
6
5
1960
1965
1970
1975
1980
1985
1990
1995
2000
REMO_C20_1
REMO_C20_2
REMO_C20_3
DWD
bc_C20_1


Jahresmittel – Niederschlag [mm/Monat]
Niedersachsen 10km (1950 – 2000)
120
110
100
90
80
70
60
50
40
30
1960
1965
1970
1975
1980
1985
1990
1995
2000
REMO_C20_1
REMO_C20_2
REMO_C20_3
DWD_REGNIE
bc_C20_1

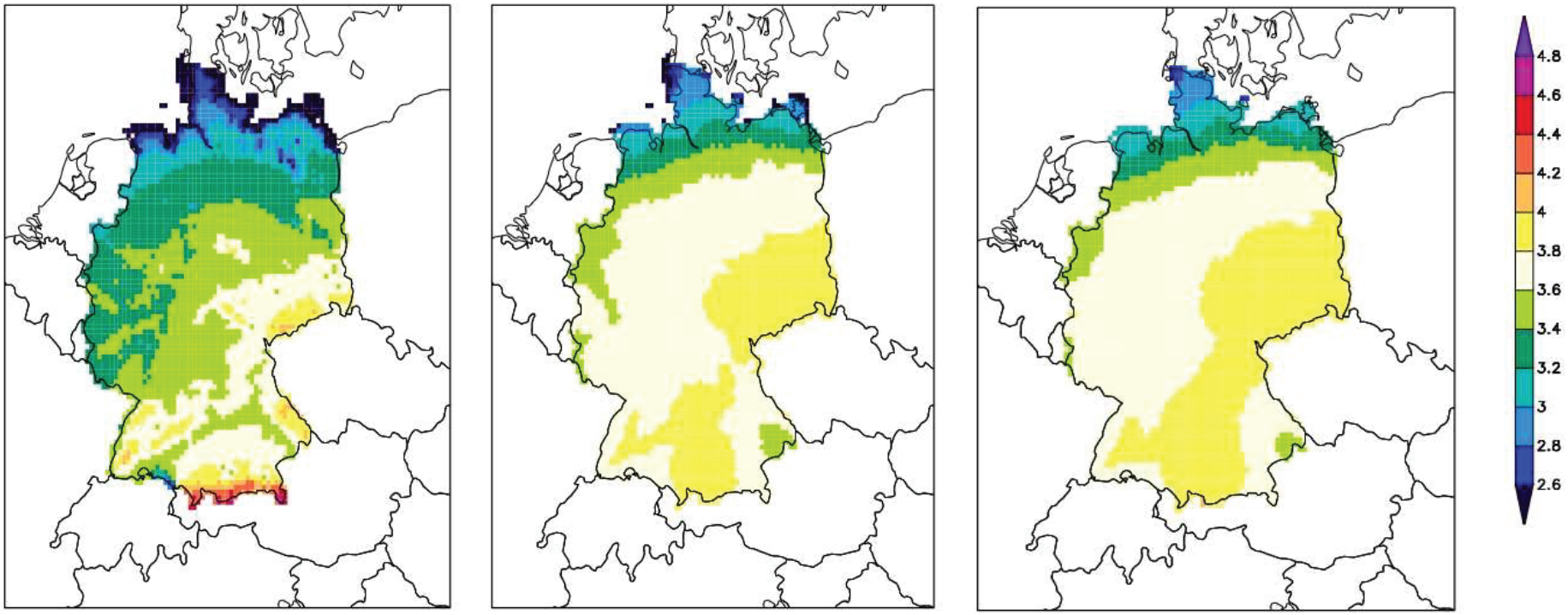

Mittlerer Jahresgang – Niederschlag [mm/Monat]
Niedersachsen 10km (1961 – 2000)
120
110
100
90
80
70
60
50
40
1
2
3
4
5
6
7
8
9
10
11
12
REMO_C20_1
REMO_C20_2
REMO_C20_3
DWD_REGNIE
bc_C20_1

Einfluss der Bias-Korrektur auf die tägliche Variabilität


TEMP2 Niedersachsen (1990)
REMO-UBA
REMO bc
25
20
15
10
5
0
-5
-10
-15
-20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

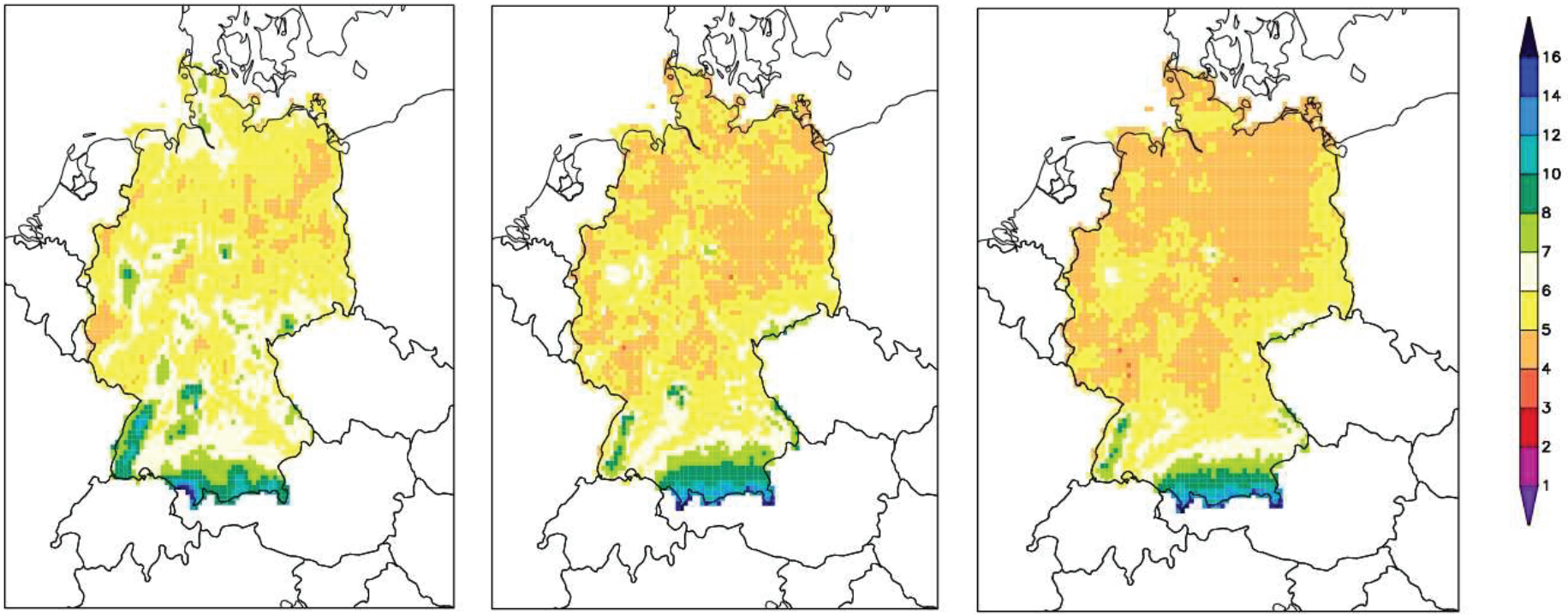

DPREC Niedersachsen (1990)
REMO-UBA
REMO bc
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

TEMP2 Standardabweichung in °C, Jahresmittel 1961-2000



REMO REMO (BC) ECA-Obs

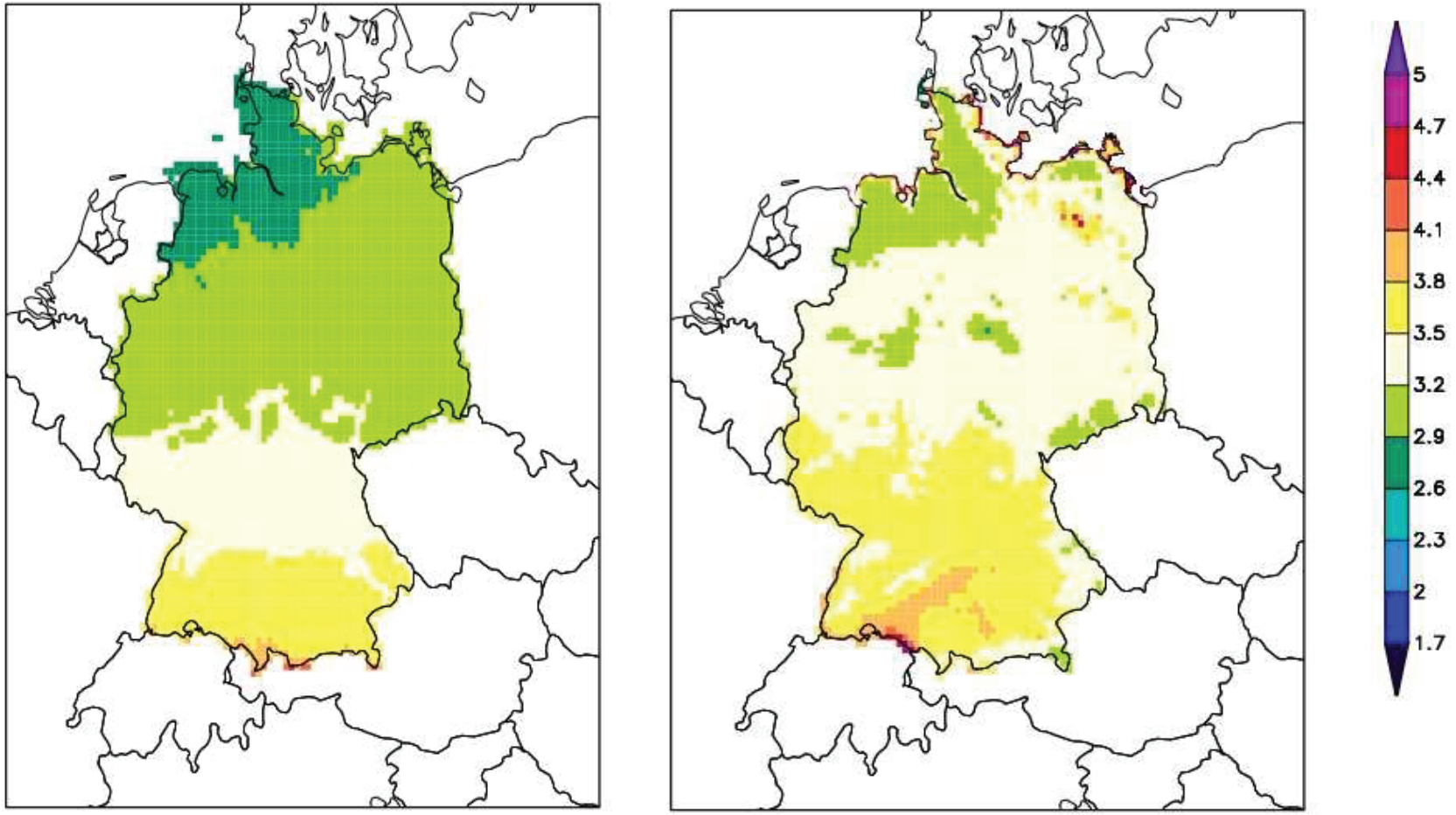
DPREC Standardabweichung in mm/Tag, Sommermonate 1961-2000



REMO REMO (BC) REGNIE

Einfluss der Bias-Korrektur auf das Klimaänderungssignal

Temperaturänderungssignal, Jahresmittel
2071-2100, Referenz: 1961-1990

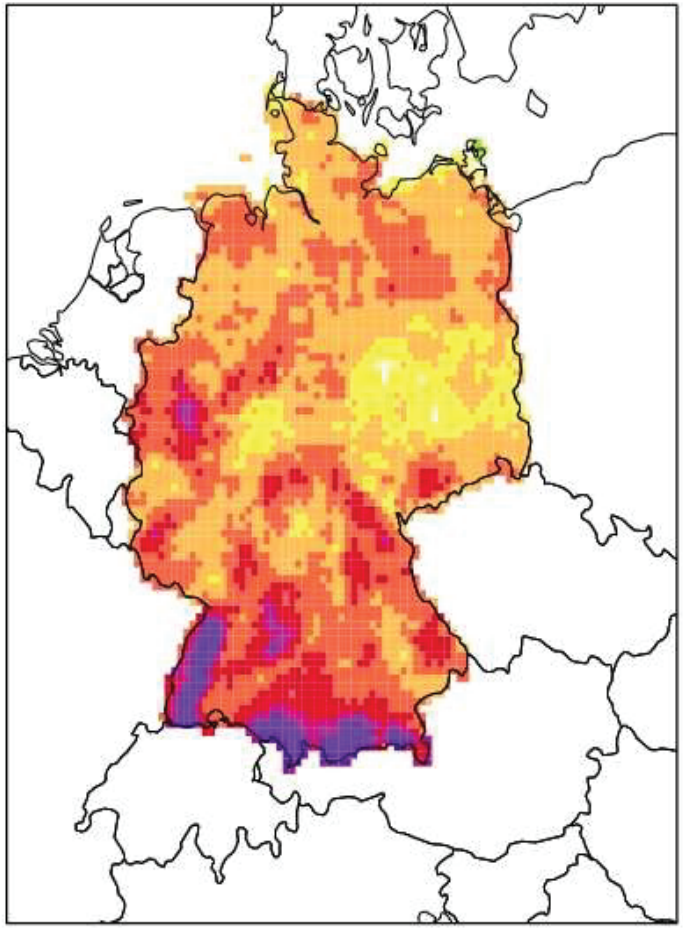


REMO

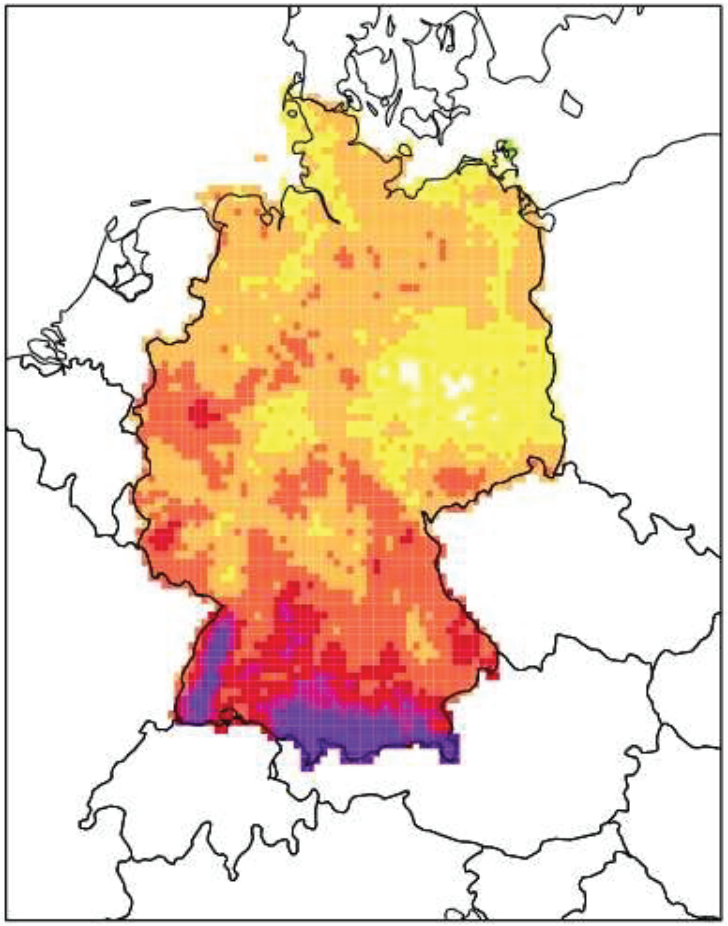
REMO (BC)

Niederschlagsänderungssignal, Sommermonate

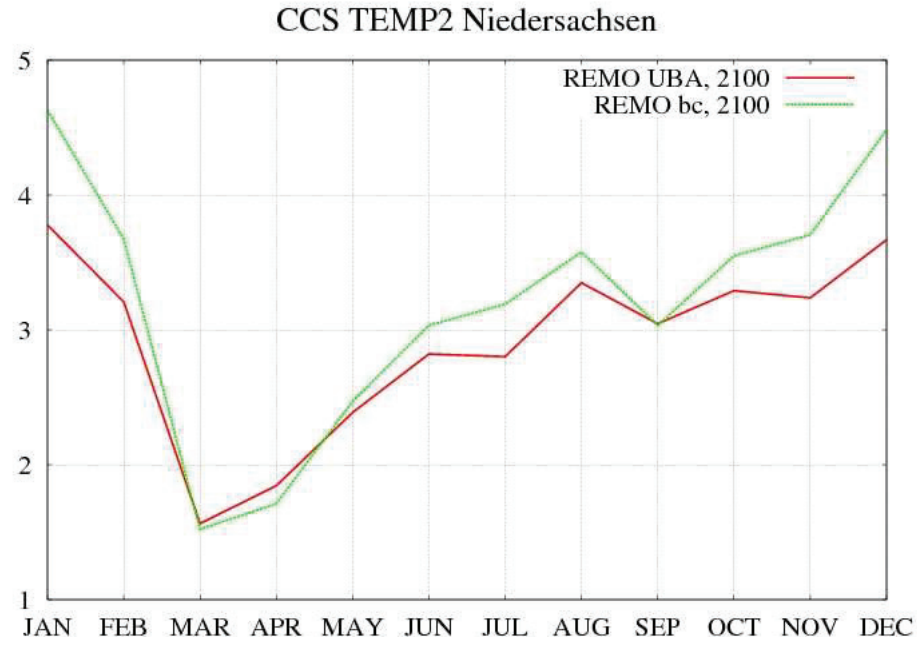
2071-2100, Referenz: 1961-1990

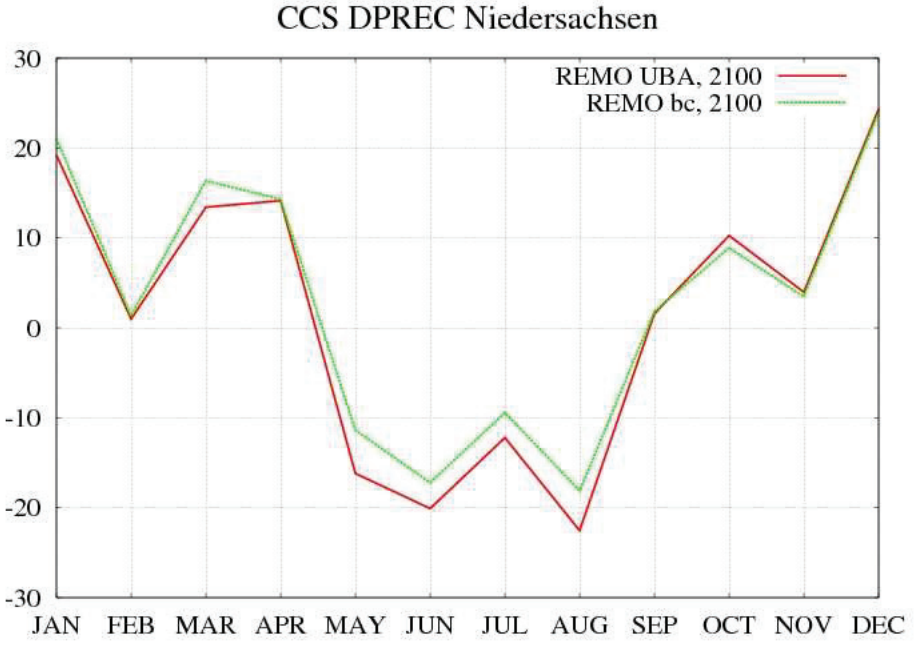


REMO



REMO (BC)

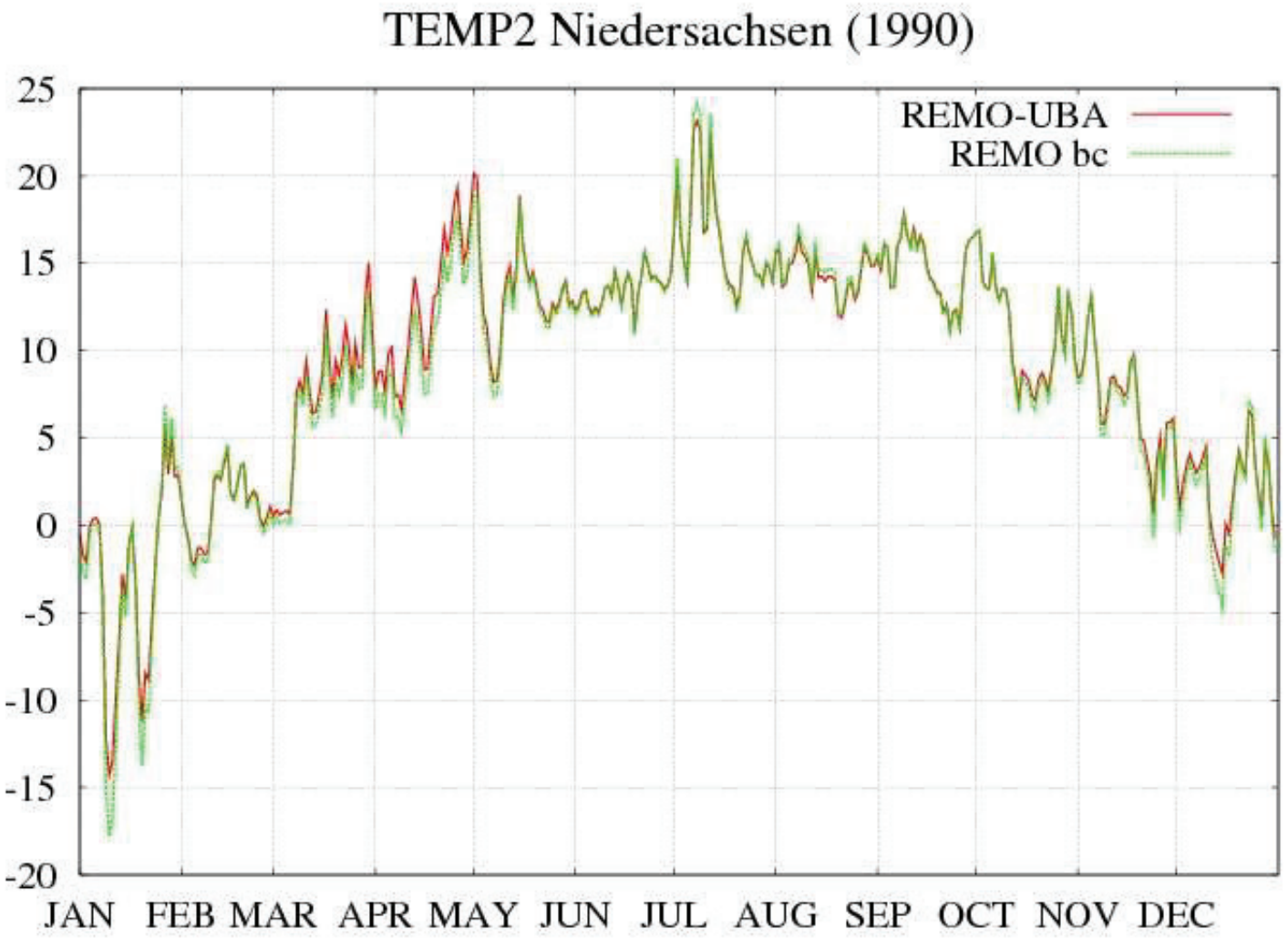




Klimaänderungssignal für 2m Temperatur (°C) und Niederschlag (mm/mon):

Zeitraum: 2070-2100

Referenz: 1961-1990


TEMP2 Niedersachsen (1990)
REMO-UBA
REMO bc
25
20
15
10
5
0
-5
-10
-15
-20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Schlussfolgerungen

- Die simulierten Jahresmittel von Temperatur und Niederschlag entsprechen nicht den beobachteten Werten, da das simulierte Kontrollklima nur eine mögliche Entwicklung des Klimas wiedergibt.
- Jede Realisierung des Kontrollklimas hat diesselbe Wahrscheinlichkeit, mehrerer Realisierungen berücksichtigen die interne Klimavariabilität.
- Eine systematische Über-/Unterschaetzung der simulierten Parameter in allen Realiserungen des simulierten Kontrollklimas deuten auf ein Modellbias hin.
- Das Klimaänderungssignal kann durch eine Biaskorrektur verändert werden, sofern nicht nur eine additive Mittelwert-Korrektur durchgeführt wird.

Schlussfolgerungen

Anpassung der Impakt-Modelle an die originalen Klimamodellergebnisse ist besser als Biaskorrektur wegen:

- Inkonsistenz der biaskorregierten Parameter zueinander
- Unsicherheiten und Annahmen der Biaskorrektur-Methode
- Unsicherheiten in den verwendeten Beobachtungsdaten

Thank you for your attention!